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UNIVERSITY OF VERMONT

AND STATE AGRICULTURAL COLLEGE

VERMONT AGRICULTURAL

EXPERIMENT STATION

BURLINGTON, VT.

BULLETIN No. 184

SEPTEMBER, 1914

Potato Scab

By.

B. F. Lutman & G. C. Cunningham

BURLINGTON:
FREE PRESS PRINTING CO.,
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BULLETIN 184: POTATO SCAB

By B. F. Lutman and G. C. Cunningham

SUMMARY

1. The ordinary scab of the potato is due to an increase in growth in the cork layer. This stimulation of the cork is produced by the growth of an organism on its surface and in its outer cell layers. Chemical substances are formed which are absorbed and which cause the cork cells to increase both in size and number.

2. Under the scab lesions, the cells often contain fat-reacting bodies of various sizes, which in some cases assume the coccus shape.

3. The organism producing scab is the one described by Thaxter as Oospora scabies but which had been previously described and named as Actinomyces chromogenus by Gasperini.

4. Actinomyces chromogenus is a wide spread organism, which is found in practically all soils, so far as known, but is most numerous in those soils which are rich in humus.

5. Parasitism is facultative and may be induced by an alkaline condition of the soil in the presence of moisture and an abundance of organic matter. Some strains may have developed this character to a greater extent than others, but no morphological or cultural characters as yet found show such differences.

6. The organism is probably spread much more through manure and humus than through scabby potatoes. However, use of the latter as seed is to be avoided (or the tubers disinfected), for the reason that they introduce a heavy inoculation of strains already strongly parasitic at the point where the new tubers are to be formed.

7. The most hopeful method of attack on the organism in the soil is to change the neutrality or slight alkalinity of the latter to a weak acidity. The use of flowers of sulphur seems also to be helpful in diminishing the amount of scab, but its use is apt to prove harmful to other crops if applied in too large quantities.

8. No varieties of potatoes seem to be wholly resistent to the disease but there are some differences as between varieties in this property. The cause of these variations is not clear.

INTRODUCTION

The present publication is a study of the potato disease known in America as Deep Scab, Common Scab, Oospora Scab, or, sometimes, as American Scab. In France the same disease, although confused with other types, is called "Gale" and in Germany, "Schorf." There are also included brief descriptions of other potato diseases which are spoken of as special forms of scab caused by organisms other than that which Thaxter (74) discovered in its relation to scab and placed among the fungi as *Oospora scabies*, but which one of us (17) lately assigned to one of the groups of the higher bacteria. These diseases will be dealt with briefly and only in order to distinguish them from the common form of scab, known to all growers in America.

Such a lengthy discussion of the subject at this time can be excused on the ground that even after so much literature has appeared, expressing so many varied and contradictory theories regarding the nature, cause, prevention and treatment of scab, the disease is still abundant wherever potatoes are grown. Indeed, there is a strong suspicion among potato growers and those interested in the question that the prevalence of potato scab is increasing rather than decreasing. Certainly wherever potatoes are grown year after year in the same soil the disease becomes more abundant; and at the present writing there is no definite, well known method for the prevention or control of the disease once it has become established in the soil.

While we possess valuable information regarding the direct cause of the disease, and also as to methods for freeing the seed tuber of the scab germs by disinfection before planting the seed in the soil, we have no exact information regarding the indirect causes—conditions which may enable the organism to become more active or abundant and which possibly at the same time tend to make the potato tuber more susceptible to the attack of the scab organism. These may be brought

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Note—The studies herein reported have been conducted by the writers at this Station during the last four years. The original suggestion of the problem, the isolation of the German cultures, and the study of the pathology of the tissues are to the credit of the senior author. The junior author has been in charge of practically the entire laboratory and field work. The authors assume joint responsibility for everything included.

Messrs. H. F. Johnson and F. S. Holden, College of Agriculture, University of Vermont, 1914, in connection with their senior thesis work, have also made contributions which have been of service, Mr. Johnson on the organisms of beet scab and Mr. Holden on the effect of scabing on the germination of cuttings. Thanks are due to Dr. Otto Appel of the Biologische Anstalt at Dahlem and to Prof. Max Koernicke of the Botanical Institute of the Poppelsdorfer Agricultural College for allowing the senior author to work in their laboratories while isolating some of the organisms; to Dr. H. T. Güssow of the Dominion Experimental Farms, Ottawa, Canada, for samples of British potatoes and for photographs of powdery scab and of potato wart disease; and to Mr. W. A. Orton of the Bureau of Plant Industry of the United States Department of Agriculture for photographs of powdery scab.

about by numerous soil conditions, such as an alkaline reaction, a high state of fertility, abundance of organic compounds, the moisture content and various other physical and chemical differences in soil, about which at present we know very little. There is a vast mass of published data bearing on these indirect causes, but it is so scattered and so contradictory in its nature that anyone who attempts to discover the truth and to separate it from the half-truths and errors has an almost hopeless task. It is intended in this bulletin to bring together in a succient form the gist of the published literature and so to present the more important results of each article as to facilitate a comparison of their likenesses and differences. Such an extensive review of the literature of potato scab may seem superfluous; certainly it has not hitherto been made so far as the writers are aware; but it must be remembered that any presentation of new data touching its prevention which failed to take into account the conclusions of previous workers would serve more to increase the present confusion than materially to advance our knowledge. The great mass of data is especially valuable, even though it is complicated and seemingly contradictory, as it has been collected by various writers in widely different parts of the country. The then prevailing lack of knowledge as to the cause of the disease naturally lessens the value of much of the earlier writings. Much literature exists as to the cause of the disease, methods for freeing the seed tuber from the causal organism, soil treatments for the purpose of preventing the malady from developing when the organism is already present in the soil, and on the problem of securing scab-resistant varieties. The American literature has naturally been carefully reviewed; that emaninating in Europe, however, is not as thoroughly presented, since much of it deals with the form which is known as powdery potato scab. The descriptions of the gross appearance of this disease resemble so closely the description of the common form of American scab that it is almost impossible to distinguish the one from the other; but the diseases are distinctly different and are produced by widely differing organisms, the powdery or European scab being caused by *Spongospora subterranea* Brunch., a myxomycete, the common American scab being caused by *Actinomyces chromogenus* Gasperini (*Oospora scabies* Thaxter), one of the thread bacteria. Not that the Actinomyces scab does not exist in Europe, or that the Spongospora scab does not exist in America. The very opposite is true. The latter unfortunately has been introduced into America and it is quite probable that the former is a native of both countries.

DESCRIPTION OF THE DISEASE

A brief introductory description will not be out of place at this point. The malady attacks the tubers during any stage of their development, from the time when they are mere buds until they cease to increase in size, but not, as some authors have believed, while they remain in the ground or after they are placed in storage. The disease first appears as a small brownish spot or stain on the surface of the potato. It was formerly supposed to originate always in the lenticels and there only, but it is shown by one of us (45) to originate on any portion of the potato, although frequently at the lenticels. It is not shown conclusively that deep scabs may arise in this way although the evidence would seem to indicate that they may. The lenticels are composed of cells similar in composition to those of the cork layer, but the intercellular spaces are large and offer an easy avenue of entrance for the fungus (figure 1). These scab spots, once started,

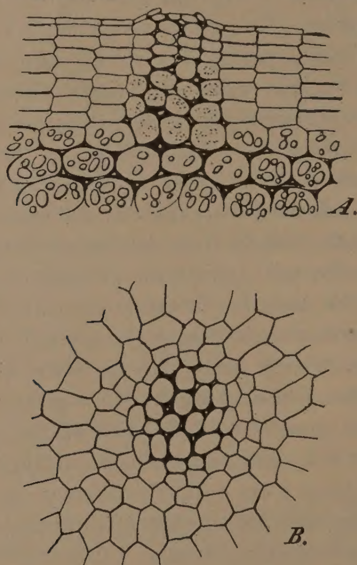


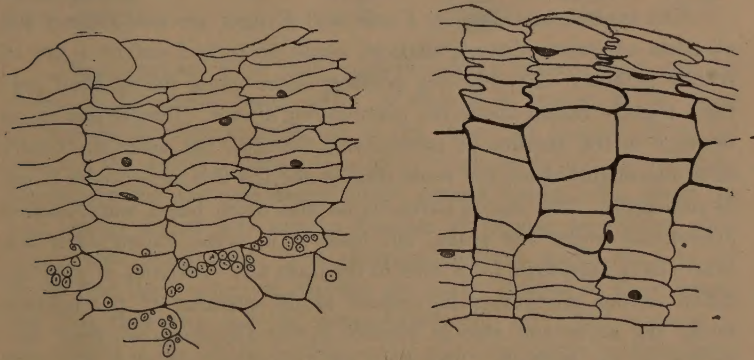
FIGURE 1.—A cross-section of a young potato lenticel. B. Surface view of same. (After Frank).

rapidly spread and increase in depth until large patches or the whole exterior of the potato may become affected, leaving very unsightly scars which, in the case of the deep or well advanced scab, may penetrate to a depth of a half-centimeter. These spots consist of

accumulated corky tissue which may be readily removed, leaving the unprotected inner parenchyma tissue exposed in a manner closely resembling the condition which exists when a scab has been removed from injured animal tissue. The diseased cells lose their starch and masses of globular bodies appear, which, according to various authors, may be disorganised tissue or fat globules (figure 2). The fact that

FIGURE 2.—Starch parenchyma cells containing fat droplets.

the mass of scab tissue may be eaten by wire worms or insects, and that these animals are often found in the affected spots, has given rise to the popular but erroneous impression that scabby potatoes are caused by their "bites." The scab is the result of the attempt of the cork cambium to protect the inner starch-bearing parenchyma tissue against the irritating action of the invading organism by the production of the new cork cells beneath the diseased part. The cork cells thus formed are abnormal in form and in the thickness of their walls (figures 3 and 4). Some of them are strongly hypertrophied and expanded while



FIGURES 3 AND 4.—No. 3. Section of normal potato cork layer. No. 4. Section of margin of a young scab.

others are crushed and distorted (figure 5). It would seem as though there were a series of formations of this nature in view of the fact

that the abnormal growths show more or less distinct layers. Frank and Krüger (21) claim that in certain types of scab a hyperplasie of the parenchyma underneath the cork occurs and that this bulge in the

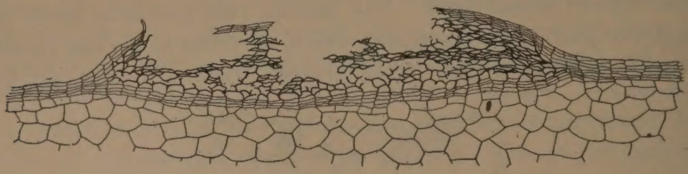


FIGURE 5.—Section of an old scab.

starch layer causes the protuberance of the spot. They claim to be able to distinguish four different types of scab, as follows:—

(1) Shallow scab, the diseased portion being on a level superficially with the remainder of the corky layer of the tuber.

(2) Deep scab, the diseased tissue sinking into the body of the tuber, a hole filled with the abnormal cork being formed.

(3) Bulging scab, wherein the abnormally stimulated parenchyma pushes the cork tissue out beyond the level of the normal skin of the tuber.

(4) Bulging deep scab, a combination of the deep and bulging forms, wherein the parenchyma is affected at the infected areas and grows abnormally, but at the same time the cork cambium sinks into this parenchyma producing a spot which is deep but also bulges beyond the level of the surrounding cork.

The types established by Frank and Krüger are not distinct and all sorts of intermediate gradations could be picked out of a bin of scabby potatoes. Freshly dug potatoes often show the scabbed portions slightly raised above the surrounding tissue. This is due to an increase in the amount of parenchyma beneath, but after the tubers have thoroughly dried for some time in the bin this appearance is not as noticeable. The starch parenchyma also often has a water-soaked appearance under the scabs, but loses it to some extent after the tubers have been kept for a time in the open air. Varieties of potatoes differ among themselves in respect to the amount of parenchyma under the scabs and also in respect to the frequency of their formation at the lenticels. The cross-section of an old scab shown in the text figure was made from a Green Mountain potato taken from storage and represents a fairly typical condition in this variety at this time.

CHEMICAL ANALYSES OF SCABBY TISSUE.

Three analyses of the peelings from scabby and clean Green Mountain tubers were made in the chemical laboratory of this Station. In one case (No. 1) the dry tubers were cleansed by means of a thorough brushing, but in the next instance (Nos. 2 and 3) they were scrubbed with a brush and water, for the reason that it was believed that the former method did not remove all the earth from the deeper scabs. The peelings constituting the second set of samples were cut deep enough to include all the diseased tissue on the scabby tubers and as nearly as possible to the same depth on the clean ones, but the peelings representing the third set of samples were much thinner. The results of the analyses are stated on the dry matter basis as follows:—

NO. 1; THOROUGHLY BRUSHED

	Clean	Scabby
Crude ash	6.85	15.29
Crude protein	18.52	21.68
Ether extract	1.07	0.84

NOS. 2 AND 3; THOROUGHLY SCRUBBED WITH BRUSH AND WATER

	No. 2		No. 3	
	Clean	Scabby	Clean	Scabby
Crude ash	5.94	9.85	8.51	11.28
Soluble ash (in hydrochloric acid)	5.65	8.47	7.91	9.59
Insoluble ash	0.29	1.38	0.60	1.69
Lime (CaO)	0.23	0.42	0.42	0.46
Crude protein	13.80	17.88	19.26	22.05
Ether extract	0.55	1.29	1.01	1.31

These analyses show that much proteinous material, ash and fat collect in the scabby areas. The fat content is greater in the clean peelings in the first analysis but in the other two analyses more fat shows in the scabby peelings. The latter result tends to confirm the indications under the microscope which usually display cells under the scab lesions dotted with minute droplets of varying size which stain brown with osmic acid. The chemical analyses would seem to indicate that these spherical deposits are partly proteid in their nature and that they may only be impregnated with oil. The increase in ash content in the scabby peelings seems to be due partly to depositions in the cell walls as indicated by the insoluble ash and also to cell remains in the cells themselves, as found in the soluble ash. It may well be, however, that some of the deposits in the cell walls are also

soluble in hydrochloric acid. A slight increase in the lime content of the scabby peel as compared with that which is clean is also to be noted, but it is not sufficiently marked to account for the difference observed in scabs occurring on alkaline soil as compared with those on neutral or acid soil.

INJURY CAUSED BY SCABBING

The vital practical question in any plant disease problem is the actual loss to producer and consumer. The potato is an almost universal article of food. Fluctuations in the volume of the crop necessarly affect the cost to the consumer. It seems scarcely possibly that potato growers and consumers recognize the vast extent of the loss caused by this malady. It is the popular notion that the injury and loss falls only on the grower and is confined to the depreciation in value due to an unsightly appearance which lowers sales prices. But the consumer also suffers. He may buy at a lower gross price, but on the other hand he experiences a considerable loss of food material otherwise available, due to the deep paring needed to remove the scabs when preparing the potato for the table. Moreover, some buyers object seriously to the peculiar earthy odor and taste which is characteristic of scabbed but is foreign to unscabbed potatoes. This quality, however, is not disagreeable to all people; indeed, many prefer scabbed potatoes because of this very odor and taste and because of their frequently increased mealy texture. This last quality is decidedly enhanced by severe scabbing. Neither taste nor mealiness are objectionable to the writers; and they have known many people who were exceptionally fond of scabby potatoes.

Beckwith (2) concluded that the use of scabby potatoes as seed decreases neither the number nor the yield of tubers but, rather, that if any effect whatever was secured the total production was greater as a result, although naturally the percentage of scabbed specimens was increased. His observations are not in line with those made elsewhere. Thus Bolley (5) in 1891 states that "the farmer is unable to judge how much greater the yield in bushels per acre might have been had the crop not been affected." The next year he cited the results of experimental trials tending to discredit the theory that increased yields followed the use of scabby seed. He stated that "while it is a common assertion on the part of potato planters that the disease does not affect the yield, that it is more often associated with a heavy yield, I am enabled from

the consideration of numerous experiments to say that the idea is wholly erroneous. In fact the yield of any given hill is always diminished. Having during the seasons of 1889, 1890 and 1891 perfected a treatment of seed tubers in so far that a healthy product could always be grown from the most badly scabbed seed tubers available, I have been able to make accurate tests of the loss in yield occasioned by the disease. Thus using for each hill tubers of equal weight, scabbed over the entire surface, planted and cultivated under like conditions, in no case has the product from such seed untreated been equal in weight to the healthy product from similar but treated seed. A consideration of all tests made during the summers of 1891 and 1892 shows that the production from such seed is diminished by the disease an amount equivalent to a fraction over one-half pound per hill or about one-fifth to one-sixth of a crop. If three to four hundred bushels per acre be assumed a fair yield it is easy to estimate the probable loss. A disease which lessens the yield from fifty to sixty bushels per acre, aside from the fact that the entire product is made unsightly and open to excessive waste in preparation for the table, is worthy of no slight effort at prevention."

Goff, (26) planted very scabby seed and seed free from scab on a soil which had been a rich clover sod. From the former he secured a yield of 199⅜ pounds and from the latter, one of 477¾ pounds.

INFLUENCE OF SCABBY SEED ON YIELDS.

(Wis. Sta. Rpt., 1892)

	Total yield in pounds	Percent scabbed	Percent slightly scabbed	Percent badly scabbed
Seed tubers free from scab..	477¾	80.6	51.0	29.6
Seed tubers very scabby.....	199⅜	73.3	56.8	16.5

Many of the plants derived from the diseased seed were weak, some developed only a few stalks, and much of the seed failed to germinate. It would seem that scabbing not only weakens the vitality but is also capable of destroying the eyes or germinating power of the seed.

Trials made in this (Vermont) laboratory indicate that the seedlings are not seriously affected so far as the germination and vigor of their shoots are concerned unless the scabs are so large and abundant that all the eyes are covered. Rhizoctonia scab seems to be much more effective in preventing germination than that produced by Actinomyces, as there is a very strong tendency for the sclerotia of the former variety to collect in the eyes.

Four lots of cuttings were selected, made up as follows:—(1) Clean, (2) with scabs but not in the eyes, (3) with abundant scabs around the eyes, (4) with scabs in the eyes. The average weight of the cuttings was approximately the same, varying from 13.5-14.5 grams. They were planted in the greenhouse on Feb. 17. Measurements made on March 24 of the longest shoots were:

(1)	Clean	6.35 cm.
(2)	Scabby but not in the eyes	6.14 cm.
(3)	Scabby around the eyes	7.6 cm.
(4)	Scabs in the eyes	6.6 cm.

No differences in vigor were observed but individual cuttings taken from potatoes which were entirely covered by ordinary scab failed to germinate and rotted in the soil.

There are two injuries which are undoubtedly more serious and more productive of actual loss to producer and consumer than is scab: viz., induced decay and lessened crop yield. The indirect influence of scab on rotting is readily understood when one notes how the protecting cork layer is cracked and destroyed, thus preventing it from serving its purpose of guarding the interior against the various saprophytic fungi which cause rotting both before harvest and during storage. This fact has been observed by various writers, but no definite statistics as to the extent of the resultant loss have been secured.

The penetration of the tuber by other fungi frequently occurs in badly scabbed specimens as is shown in figure 6. Bacteriological plates

FIGURE 6.—Longitudinal section of a scabby potato showing the penetration of the tuber by other fungi following scab.

made on synthetic agar from such penetrations showed that the majority of these fungi were various forms of Penicillium, Aspergillus and Fusarium. These fungi rot the tuber slowly while it is held under

good storage conditions; but when a cutting is placed in the soil it quickly succumbs to their attack, especially if the season is a wet one.

From the above discussion it is seen that the injuries and losses caused by potato scab are :

(1) Depreciation in value due to the unsightliness of the disease.

(2) Loss caused by the extra thick paring necessary when preparing the potato for table use.

(3) Changed taste and odor due to the presence of scab.

(4) A shortage in crop yield when scabbing is abundant.

(5) Increased liability to tuber decay both before and after harvest.

No accurate estimate of the actual monetary loss can be made. The factors involved are too numerous and complicated. It would run far into the millions of dollars for the country as a whole and into the tens or perhaps hundreds of thousands for Vermont. It seems clear that potato growers needs must in the future pay more attention to the scab problem.

NAME

The name of this disease, potato scab, is well chosen, but it is to be regretted that other maladies of a similar nature, yet caused by distinctly different organisms, have been called potato scab, various descriptive terms being added, such as black scab, powdery scab, silver scab. It seems advisable that some definite name should be applied to this disease so as to distinguish it from the other forms. It has of course been called common scab, but such a name is only applicable in the strict sense of the word so long as this disease remains the most common, or the best known of its type, which already exists or is likely to develop in the future. Thus, for example, if the common European form which is caused by *Spongospora subterranea* should become common in this country—as unfortunately it bids fair to do at this writing—and at the same time become more important, it would be recognized in the popular mind and by the practical grower as the common form of scab, and hence the term "common scab" would thus be a misnomer introducing error and confusion. The disease cannot strictly be called "American scab" since it not only exists in Europe but is probably native to Europe, Africa, Australia, and America and possibly to practically all countries where the potato, *Solanum tuberosum,* is grown. In the absence of a better name and of one which should be of permanent value under all circumstances, it seems advis-

able to speak of this form of scab either as the "Actinomycosis" of the potato, or as "Corky Scab." This designation and description of the disease is important as there are prevalent at the present time in this country and in other parts of the world at least two other fairly common diseases known by the same general name of scab, viz.: Rhizoctonia Scab and Powdery Scab.

Rhizoctonia scab of the potato is nearly as common throughout the United States as is Actinomycosis, but may be readily distinguished from it even by a superficial examination. The spots it produces are black and hard in contrast with the brown loose-textured actinomycosis spots, while they adhere rather loosely to the corky layer of the potato. Very little penetration of the host plant seems to occur and the amount of nutrition derived from it must be relatively small. The amount of loss caused by this disease seems comparatively small throughout New England as compared to the injury and loss attributed to this fungus in the Middle and Western States. It is believed that mixed infections of Rhizoctonia and Actinomyces often occur, but the former seems to be attached to scab spots formed by the latter and to mingle its mycelium with the mass of brownish cork resulting from the stimulus of the *Actinomyces chromogenus* to the cork cambium. Rhizoctonia scab is produced by the sterile fungus *Rhizoctonia solani* (*Corticum vagum*).

Powdery scab of the potato has recently been introduced into Canada and the United States from Europe. It has attracted considerable attention on this side of the water and a quarantine has been established against the importation of potatoes from various parts of Canada and Europe. More recently the disease has been found by Morse (51) and by Melhus (48) to occur extensively in certain counties in Maine. Since Maine seed potatoes are used extensively in many of the states, we may expect to meet this form of scab in almost any section of this country within the next few years unless properly enforced quarantine and inspection regulations control its spread. This type of scab is so similar in superficial appearances to that produced by Actinomyces that it is not possible to distinguish the two apart with certainty without the help of the compound microscope. There seems in this disease to be a more definite limitation of the scabbed area, the spots have a little more the appearance of a shallow crater and the scab tissue is slightly friable. The fungus, *Spongospora subterranea,* related very closely to the slime-moulds, or possibly one of them, is the cause of this type of scab.

OTHER PLANTS SUSCEPTIBLE TO SCAB

Actinomycosis or corky scab, although primarily a potato disease, attacks other plants, as has been shown by various authors. As early as 1864 it was recognized that a similar disease of the beet was produced by the same agency, supposed to be marl. Bolley (6), after the discovery of the now recognized cause of the disease, showed by experimental inoculation that the scab of the beet was identical with that of the potato and supposed that such plants as turnip and radish might also be affected. Arthur and Golden (1), working independently, made the same observations and confirmed Bolley's findings.

Halsted (32) four years later carried on trials with various crops to determine their susceptiblities. These were planted together with potatoes in soil known to contain the scab organism. The potatoes when dug were found to be badly infected with scab. Careful examination of the several species indicated that beets, turnips and radishes were susceptible, and that four varieties of the Solanaceae, viz., *Datura stramonium,* tobacco, tomato and pepper, were not susceptible. Sweet potato, artichoke, chufa, cardoon, chickory, salsify and parsnip, all fleshy root plants, seemed free from infection.

Bolley (6) found that the disease could be conveyed to beets by growing them in soil where scabby potatoes had been grown. H. F. Johnson, working in this laboratory, has isolated organisms from scabby beets which agree in all cultural characters with those obtained by the writers from potatoes. There seems to be no reasonable doubt that the disease as it appears on potatoes and on beets is identical.

EARLY STATEMENT AS TO SCAB

Since the organism is believed to be native to the soil, and, according to our present knowledge and observation, exists almost universally in soil, especially in those which are well cultivated and rich in humus, the disease is probably as old as is potato culture. Doubtless it has existed both in America and in Europe since first potatoes were grown. And it is possible, if not indeed probable, that the disease may be common on uncultivated specimens.[1] The first mention of the disease was made in Loudon's Encyclopedia of Agriculture (1825) as follows: "Scab, that is to say the ulceration of the surface of the tubers, has never been explained in a satisfactory manner. Some attribute it to

[1] Wright states to the authors that he observed no indications on uncultivated potatoes during his South American potato collection tour for the Federal Department of Agriculture.

the ammonia from the dung of the horse, others to alkali, and certain others to the use of wood ashes on the soil. Not using diseased seed and planting in other soil are the only known means of preventing the malady."

PLANT PARASITES AS THE CAUSE

The earlier descriptions apparently were made to fit the type then common and have little to do with that discussed in the present bulletin. It is of interest, however, to note that von Wallroth was the first to assign to the disease a fungus origin and to give that fungus a name. In 1842 he writes: "The much discussed disease of the potato discussed in economic writings I have known for a long time under the name of potato scab, potato wart, scab disease, brown stains and potato rot as a kind of vegetable rust." He supposed it to be caused by *Erysibe subterranea,* while other workers classified it as *Uredo, Ustilago* or *Caeama.* Von Wallroth probably had at hand the present European form caused by *Spongospora subterranea.* Many scientific workers and practical growers were inclined to question his findings and to suggest various mechanical, physical and chemical stimuli as the cause of the abnormal growths. Much experimental work was done during the succeeding half century, but relatively little advance was made other than to list the results of these numerous trials and to accumulate evidence as to the influence of lime, fertilizers, manures and various chemicals when applied to the soil or to the seed tuber. All this tended to befog the situation and to substantiate the theory generally held up to 1890, that the disease was due to some mechanical, chemical or physical cause, or to the attacks of nematodes and various insects, many of which have been described in detail.

The theory of its foreign origin disputed the field with the various irritation theories until 1886 when Brunchorst (9), describing the disease as it existed in Sweden, showed that the scab with which he worked was caused by *Spongospora subterranea.* He assumed that all forms of scab, whether of European or of American origin, were the same and caused by the same organism, while as a matter of fact he was studying only the type now known as "powdery scab." His conclusions were not fully accepted as to certain forms and it remained for Humphrey (38) in 1889 to call attention to the fact that all forms of scab were not alike. He carefully compared potatoes secured in America and from Germany through Sorauer, as well as photographs and descriptions secured from Brunchorst of the Swedish "skurv," and con-

cluded that the German "schorf" and the English and American potato scab are one and the same, but that "skurv" is a distinctly different disease and that Brunchorst's assumption that all forms are similar and caused by *Spongospora subterranea* was incorrect. This distinction, as pointed out by Humphrey, is now generally accepted.

After numerous investigators had given up the search for a parasitic cause of corky scab and after nearly every worker in this special field had announced that experimental evidence indicated that either mechanical, physical or chemical effects and not a living organism were causal, two American investigators demonstrated its parasitic origin. Despite the ample proof which their statements afforded, many were inclined at first to doubt their assertions. This is not surprising since the causal organism is so dependent upon secondary conditions present in the soil that it may not always produce the disease. It is now thoroughly recognized that a soil may be infected. even seriously infected, and that potatoes may be grown thereon without much if any danger of scab. It is also well known that under certain conditions such a soil may be induced to grow badly scabbed potatoes. This simply means that some soil amendment has brought about conditions which increase the activity of the causal organism and hence the increase of scabbiness, the amendment being the exciting but not the direct cause.

Bolley (4) by the use of bacteriological cultural methods was able to isolate from the tissue beneath the scab a bacterium which produced the disease repeatedly when inoculation were made with pure cultures and also more vigorously when infusions direct from the scab were used. The organism was a short, motile rod, varying but slightly in size, usually .7x.7-1 microns. In old cultures it appeared more spherical or coccoid, .7x.8-.9. In rapidly growing cultures it was free from motion. Chains with from 4 to 6 and even 10 to 12 segments were present. In broth cultures at room temperature slight clouding appeared in from 30 to 40 hours and a pellicle formed in about 7 days. Gelatin plate cultures gave a slow growth of disc-shaped and, later, concentric colonies with a yellowish color. Gelatin stab showed a funnel-shaped liquefaction. Growth on potato and agar cultures was white and later yellow but not characteristic. The optimum temperature was from 37 to 40° C., division at this temperature taking place in from 15 to 30 minutes. The habitat of the organism was found to be the tissue beneath the potato scab lesions. Bolley speaks of its arthrosporous character and for this reason considers it a true bacterium, regardless

of its distinct motility. It is needless to discuss this organism further than to say that if it did produce scab, the disease is an unimportant type. It has not since been seen and, moreover, Bolley himself has been unable to reisolate it. His later publications lead one to believe that he doubts its importance.

Scarcely three months after the announcement of Bolley's observations, Thaxter (73) described a new fungus-like organism which he claimed was the cause of the deep form of potato scab and with which he was able to produce the disease under test conditions. While his observations did not disprove Bolley's findings, they led to quite different conclusions. It is now generally accepted, even by Bolley himself, that the organism called by Thaxter *Oospora scabies* is the chief if not the only cause of the common form of scab.

Thaxter's attention was first attracted by the presence of a peculiar gray mold-like growth on the diseased spots. From these he isolated and cultivated the organism which he characterized (74) as follows:

"*Oospora scabies.* Vegetative hyphae, brownish .06-1 microns in diameter, curving irregularly, septate or pseudoseptate, branching. Aerial hyphae at first white then gray, evanescent, breaking up into bacteria-like segments after having produced single terminal spiral spores (?) by the coiling of their free extremities. Forming a firm lichenoid pellicle on nutrient jelly and usually producing a blackish-brown discoloration of the substratum on which it grows. Causing the disease known as 'scab' on potato tubers and a similar disease of beet roots."

Thaxter's findings have been confirmed by Arthur (1) and others, including Bolley who was unable to confirm his Indiana work but readily isolated the Thaxter organism. He writes: "The first cause of deep scab as studied here is found to be a plant organism of very minute character which attacks the surface of the young growing tubers, eroding, irritating and blackening the adjacent tissue, and is identical with that associated with the disease in the east. . . . . . Pure masses of the scab plant when grown on nutrient gelatin, free from all other germs, when transferred to the surface of healthy growing potato tubers will invariably produce the disease at the point of application." It is interesting to note that the potatoes from which Bolley isolated his bacterium while at Indiana were secured from the Massachusetts station and that the disease according to him was identical with the Indiana form, indicating that it was common to the East and the Middle West. One naturally queries whether there may not be

more than one form of the disease and more than one causal organism. Bolley's results suggest such a query and it may be best answered by quoting from one of his later papers (5). "As to the question whether two distinct diseases exist, I may say that I am even yet much in doubt. This would at first glance seem to imply that I doubt the accuracy of my last year's infection tests. This is, however, in no wise necessarily so, as various other circumstances are involved which render such an assumption on my part as yet comparatively groundless. Certainly, in common with those conversant with the details of such work, I recognize that there are many possibilities of error; but that work was too carefully done to admit of any change in the assertion made in the report of the same, other than in so far as they assume only one form of the disease, a point which with me must remain in doubt until I have been able to do work under conditions similar to those under which the work was then carried out. The organism with which I then worked, a true bacterium, was undoubtedly very different from that pointed out by Dr. Thaxter as the originator of 'deep scab,' the one which upon coming to Dakota I was immediately and readily able to recognize as the active agent in the disease here. Furthermore, in so far as cultural characters and infection tests have been conducted this year, affirmative results have been attained only with the latter form, the bacterium not being found. I have, to that end, to date used only the disease as found here, a form very much more pronounced than that studied last year, possessing some characters of action not then noticed. How many of these were present but not then noticed, and how much they are due to soil differences, I can not say. Certain it is that it is hard to draw the line between the surface and deep form of the disease, from a consideration only of gross characteristics unless it be in the pink coloration of the surrounding living tissue not then noticed.[1]

That, in the Indiana work, I many times under apparent exclusive infection conditions induced potato scabs, recognized as such by all who saw them, there is no question. Considering then for the time that the disease as generally understood has but one origin, there are two possible ways for accounting for those results: First—Error in formation of the infection material so that other germs than the bacterium were present (possible but not probable) ; Second—That the

[1]The writers have repeatedly observed all stages of surface and deep scab in the same field, in the same hill and on the same potato. It is barely possible that the surface and deep forms may be caused by different strains of the same organism, some more active or virulent than others, or that early infection or peculiar soil conditions in the immediate neighborhood of the lesion may have brought about the difference.

bacterium used (which was undoubtedly parasitic in the potato plant) might under the conditions of the inoculations produce the scabbing which in nature would not occur. This I deem very probable from the then determined capabilities of the bacterium to penetrate living tissues of the plant even to parts of the young growing stem. The question is yet an open one. I can only regret that my authentic material was unavoidably lost and await opportunity to give it further tests. I may say, however, that the parasite studied this year acts much more rapidly in artificial infection than did the bacterium and there is little question that it is the originator of the chief amount of potato scab."

With the discovery of a parasitic cause of the disease, renewed attempts were made to prevent the spread of scab by means of tuber disinfection. This procedure has been fairly successful, formaldehyde being used for the purpose as a gas and as a weak solution in water. Other chemicals have been used but less extensively. Many workers have contributed to perfecting this method, but much of the credit is due Bolley (5) for so ably presenting it to the popular mind.

OTHER THEORIES REGARDING THE CAUSE OF SCAB

While the individual theories advanced as to the cause of potato scab are almost as many as the men who have investigated the subject, they naturally group under four heads, viz.: (1) Mechanical irritation; (2) insect and other animal parasites; (3) chemical erosion or irritation; (4) excessive moisture. It is now clearly understood that these are not direct causes, yet they may be considered as secondary, conditional, indirect causes; that is to say they are conditions which tend to favor the growth and to accentuate the effects produced by the direct cause, the organism. The influence of these conditions is so important that stress may well be laid upon these secondary causes.

Mechanical irritation: The theory that scab was a resultant of mechanical irritation was based on popular observation and lacks any considerable volume of experimental evidence. It having been noted that soils containing such materials as lime, rubbish, builders' refuse, refuse from ash-pits, street sweepings, and similar materials were apt to produce badly scabbed potatoes, it was reasoned that these were cause and effect. Smith (62), the chief advocate of this theory, agreed that these substances caused mechanical injury by producing a thick corky layer. He states that "on visiting this position (where diseased tubers are found) the irritating substance in the soil will usually be seen."

Insect and other animal parasites: This theory is based largely on the fact that insects of various species, nematode worms, wire worms, etc., are often found feeding on diseased potatoes, many of them seeming to prefer the diseased or decaying tissue. Beckwith (2) placed several dozen millipedes in a glass vessel containing growing potatoes and concluded that "millipedes do not feed upon sound tubers, their food consists of decaying vegetable matter. The presence of millipedes in the hill with scab tubers was due to the scab, they being attracted by the decayed portion which they desired for food and the scab is not due to their presence." Hopkins (36, 37) also describes a beetle *Epidapus scabies,* which he claims is capable of causing scab. The injury produced by these insects is, however, of the nature of erosions of the tuber surface which sometimes so closely resemble the common form as to pass for it. Orton (55) discusses a disease due to the attacks of ellworms, *Heterodera radicicola,* in the western and southern states, which might be confused with potato scab.

Chemical erosion or irritation: This theory has more or less in common with the mechanical theory in that the chemical action of certain substances is held to cause the potato to produce an abnormal quantity of cork cells. It was believed that this was brought about by the caustic action of lime, ashes and various fertilizers. The use of barnyard manure and of marl and lime has long been popularly associated with potato scab. As early as 1864 farmers and practical growers so explained the disease and believed that the scabbing following liming did not reach its maximum until 10 years after its application.

There is a strong likelihood, almost certainty, that these substances do tend to encourage scabbing where the organism is present, because of their tendency to correct acidity and because the scab organism requires a slightly alkaline or nearly neutral medium in order to thrive. This theory was further supported by Humphrey (38) who says: "Several years' observation at this station (Massachusetts) points also to the correctness of the view that the cause of our trouble is to be sought in peculiar physical or chemical conditions of the soil." In this connection see Sorauer's statement on pages 22 and 23.

Excessive moisture: This theory is based upon the fact that moisture on the lenticels tends to produce an abnormal growth of corky tissue at such points and that the actual amount of scabbing on potatoes grown on wet soils is greater than those grown on dry soils. According to this theory Caspari (10) supposed that the disease was induced by the action of moisture on the lenticels. They increase in

size and finally burst the cork rind, thus giving rise to the formation of scab, or, rather, to a structure capable of producing scab. These tissues continue to degenerate underneath the cork so that a more or less thick scab is produced, due to the replacement of the starch cells by the cork cells forming the lenticel. Scab due to a local increase in the cork formation, does not occur in the wart or on tubers produced in the air. Later Stahl in 1879 shows that if transpiration is stopped the lenticels increase and may develop into scab spots. Among the earlier advocates of this theory was Schacht (60) who says: "As the lenticels develop by the formation of new cork cells they break through the skin and are transformed into irregular cavities with ragged borders or long irregular cracks which are always lined with a layer of cork....I must here regard heavy moisture of rich soil the first cause." Frank (20) and Giersberg (25) also support the excessive moisture theory. Beckwith (2) concluded that irrigation during a dry season increased scabbing, in one test from 31 to 48 percent, in a second test, where barnyard manure was also added, from 22 to 71 percent, while when barnyard manure was used without irrigation scabbiness increased only from 21 to 30 percent. Numerous other citations of a similar nature might be made. Apparently excessive moisture does tend materially to increase scabbing, but it must be remembered that it is only a secondary cause inducing but not producing scab.

The early theories held in Europe regarding the cause of scab are carefully and briefly reviewed by Sorauer (63) and direct translation seems in place. In discussing the influence of moisture on the lenticels relative to the production of scab, he writes:

"That this hypertrophied formation of lenticels is dependent upon an unusual amount of moisture we conclude from the following facts: During a long continued season of wet weather the lenticels of alder trees stand out in the form of thick white protuberances; by immersing a piece of cherry stem in water a luxuriant growth of cork can be artificially produced; finally, in case of the potato, these cork warts may be actually produced by keeping the potato for a long time in moist air. Nobbe found, by a water culture of the potato, that the tubers grown in water produced small warts while still very young. These warts were caused by a local increase in growth in the cork formation, and were not present in tubers produced in the air.

The view that superfluous moisture at an unseasonable time is the cause of the increased growth of cork that produces scab is indorsed by Caspari and Schacht as well as by Frank. A later work by Stahl established the fact that if transpiration is stopped, lenticels develop beneath the stomata. On the contrary, farmers assert that in the majority of cases the adding of lime and marl to the soil, and manuring with dung and street sweepings causes the disease. Kühn agrees with Wallroth in the opinion that the formation of scab is caused by a fungous growth (*Erysibe subterranea*, Wallr.).

On the other hand, iron, when present in a low state of oxidation, is considered injurious. In a field of potatoes at Newmarket three rows which had been marled with light colored earth mixed with iron oxide were found free from scab, while the rows that had received marl that was dark colored from the presence of peroxide of iron were very scabby.

The assertion has frequently been made by practical farmers that fresh animal manure causes scab, especially in the thin-skinned varieties, and that the disease makes its appearance after an application of soapsuds, while after a strong application of potash, which had proved very injurious at another time, the tubers were free from scab.

I believe that Wallroth's opinion is erroneous. It is true we find fungous formations upon the dead parts, but none that attack healthy tissues. Many have objected to the view that scab is caused by adding lime, marl, or dung to the soil, but when it comes to final definite results, the reports vary in regard to secondary circumstances. For example, one person says that scab made its appearance after the application of marl, but that the greatest development of the disease did not occur the first year, during which the potatoes were perfectly healthy, but that the disease steadily increased during the ten following years. The same account claims that beets are similarly affected by marl. It is interesting to note that where the marl was not used the potatoes showed no scab. In Posnia, in the seventeenth century, marl was frequently added to the loose soil of large estates for the purpose of raising *Medicago media*. This was generally preceded by two crops of potatoes, which were always marled. In spite of this, scab never made its appearance if the marl was drawn before winter and thoroughly mixed with the soil. The same experiment was recorded a year earlier in Saxony in the Zeitschrift des Landwirthsch. Centralvereins (p. 219).

Heiden reports a very thorough experiment at Pommritz in regard to the use of lime. A piece of new land was given heavy applications of lime (3,600 pounds to the acre), six times between 1868 and 1878, and in 1878 the land bore potatoes after a fresh application. The potatoes when gathered were completely free from scab. It will be seen that in this ground there was lime of different ages, from the fresh to that ten years old, and no injury resulted.

Contradictory as these results appear, they may nevertheless be harmonized if the theory should be confirmed that the frequently occurring secondary action of lime may be the dangerous agent that causes the death of the growing cork cells. Heiden directs attention to the fact that the ammonia already contained in humus is set free by the lime when a great deal of lime is used, and that the soil is not at that time able to absorb all the ammonia that is set free, a part of it escaping. This surplus ammonia will be very apt to destroy the loose cork cells within the lenticels and cause the cork formation to penetrate farther into the tissues. The ammonia will become harmless only when oxidized into nitric acid, and we have a positive statement in this direction. Kraus-Kriesdorf mentions the experiments of Dr. Schreiner, who found that scabby potatoes were very abundant in almost pure quartz sand which had been manured with ashes, pulverized turf, and nitrogen in the form of ammonia; but when in the form of nitric acid no such effect was produced. A quartz sand, without manuring, or with the ashes alone, did not produce scabby tubers, even when mingled with turf. Iron filings, iron oxide (turf ashes rich in iron) may perhaps act indirectly by checking the formation of nitric acid."

THE RELATIONSHIP OF THE POTATO SCAB ORGANISM TO THE HIGHER BACTERIA

A study made at this Station of the organism causing the corky scab of potato, *Oospora scabies* Thaxter, has resulted in the conclusion that it is related to the higher bacteria. This view was originally suggested by the resemblance of its cultural and morphological characters to those of soil organisms of the *Streptothrix* type. This view

was expressed in a paper read by one of us (G. C. C.) before the American Phytopathological Society in 1911 and has since been accepted by various workers.

A large number of organisms of the *Actinomyces* type have been isolated at this Station from soil, potato scab, and various other sources. Many of the available species of this group have also been secured from Kral's laboratory and are under study. Some of the organisms were isolated from potatoes secured from England, Holland, Belgium and Germany and three strains were isolated by one of us (B. F. L.) in Germany and were sent to this laboratory as pure cultures. A careful laboratory study of these organisms isolated from the potato scab shows them to be identical in every characteristic but one (that of spore formation in a few strains) with the organism described by Thaxter as the cause of the disease. The organisms have been isolated on various media, chiefly plain agar, Clinton's lima bean agar, potato peptone agar and potato glucose agar, all of which are alkaline or, at least, only slightly acid.

In the following description of the cultural characters of the causal organism, cultures from four sources were used. These were designated as Nos. 1, 150, 151 and 14. Nos. 1 and 14 were isolated from Vermont potatoes in this laboratory; No. 150 was obtained from tubers at Bonn, Germany and was isolated in the laboratory of the Botanical Institute of the Poppelsdorfer Agricultural College; No. 151 was isolated at the Biologische Anstalt at Dahlem near Berlin from potatoes grown in the garden of that institution. The minor differences noted between these strains will be found in the following description of cultural characters. All were found capable of producing scab on inoculation. Numerous other cultures in addition to these four were carried through the bacteriological chart, but the four strains named were selected for this description.

Summary of Characters of Actinomyces Chromogenus

I. Occurrence and Importance

The organism occurs in the soil and is the cause of potato scab as described by Humphrey (38), Thaxter (73) and Bolley (3). An increased cork formation results in a surface or deep scar resembling a scab. The organism is known to cause the potato scab in Europe, America, Australia and Africa. It may be found living saprophytically in most soils but is more abundant in soils rich in humus and those with an alkaline reaction.

II MORPHOLOGY

1. *Form,*—a thread or filament .05 to 1 microns in diameter, long and branched, wavy or curved, irregularly segmented and capable of forming aerial hyphae which break up into gonidia or short cells resembling bacilli.

2. *Endospores,*—not found; no indications that they are ever produced.

3. *Gonidia,*—short segments of the hyphae or mycelium form by the segmentation of any part of the mycelium either in the depth of the medium or on the surface, usually more abundant on the surface, giving the colony an ashy gray, cretaceous appearance; not always present and usually more common in older cultures.

4. *Motility,*—non-motile.

5. *Capsule or sheath,*—both absent.

6. *Involution forms,*—a tendency to produce aerial gonidia is present in old cultures; the mycelium also becomes degenerated and contains granules which stain deeply while the mycelium does not stain readily.

7. *Staining reactions,*—organisms stain readily with the ordinary stains, negative to Ziehl-Nielsen's acid-fast stain, positive to Gram's stain.

III. CULTURAL CHARACTERS

1. *Agar stroke,*—growth slow, abundant, spreading, flat raised, contoured, rugose, verrucose, opaque to translucent and straw-colored, coriaceous; medium browned.

2. *Agar plate,*—growth slow, round, irregular, lichenoid, contoured, rugose, raised, umbonate, entire, filamentous and, later, amorphous; medium browned.

3. *Agar stab,*—abundant at top, slight along line of puncture as beaded colonies.

4. *Gelatin stab,*—growth slow, best at top, very little along the line of puncture, beaded; liquefaction saccate to statiform, beginning in 5 to 10 days and continuing very slowly.

5. *Gelatin,*—same as agar colonies.

6. *Nutrient broth,*—growth at the surface and slow, ring and later pellicle formation; sediment abundant, compact, and flocculent; broth never clouded.

7. *Potato plugs cooked,*—growth slow but abundant, spreading, flat, raised, umbonate, contoured, rugose, glistening, some strains creta-

ceous, thick and coriaceous; color of growth and potato a dark gray to almost black.

8. *Plain milk,*—growth slow and at the surface as a ring and a wrinkled pellicle; milk slowly digested without coagulum, browned and turned alkaline.

9. *Litmus milk,*—litmus intensified, turned to a tea-brown, slightly and slowly digested; sometimes acid is produced.

10. *Turnip plugs cooked,*—growth slow at first, abundant, spreading and beaded, flat raised, verrucose, umbonate, glistening; other strains cretaceous; color creamy, orange to greenish gray, coriaceous; turnip may or may not be slightly browned.

11. *Carrot plugs cooked,*—growth slow, abundant, resembling growth on turnips.

12. *Beet plugs cooked,*—growth neither so rapid nor so abundant as on turnips, and darker.

IV. PHYSICAL AND BIOCHEMICAL CHARACTERS

1. *Indol production,*—generally absent.

2. *Acid production,*—negative or seldom produced.

3. *Ammonia production,*—moderate quantity, varying from 8 to 12 cc. in terms of N/1 HCl per litre.

4. *Gas production,*—negative.

5. *Toleration to acids and alkalies,*—best growth in slightly acid or neutral medium; quite sensitive to larger quantities of either acid or alkalies.

6. *Temperature,*—best growth at 25° C., slow growth below 18° and above 37½°; thermal death points: No. 1, 50-54° C., No. 14, 49-50° C.; No. 150, 49-51° C.; No. 151, 50-51° C.

DETAILED DESCRIPTION

MORPHOLOGY

Form of filaments: On the common forms of culture media the morphology is quite consistent, the organism appearing as long irregular filaments (figure 7), the branches interlacing to form at first a gelatinous mass which soon becomes tough and leathery. The diameter varies slightly from .5 to 1 micron, but the length naturally displays great variation. At first few segments can be observed, but on dry media, or in older cultures, the septae are more numerous. The aerial gonidia which are formed are segments of the filaments separ-

ated by crosswalls from ordinary hyphae. The segmentation of the filaments is observed with difficulty in water mounts, the cross walls in the filament being scarcely visible or not at all, while the segmentation where gonidia are produced may be readily observed. The septae are seen more distinctly after staining with such stains as carbol-fuchsin and Sterling's gentian violet, followed by a partial decoloration with alcohol. Thaxter observed segmentation after staining with iodine. Under unfavorable conditions and in old cultures the protoplasm is often more or less disintegrated, similar to that observed in old cultures of *Mycobacterium tuberculosis* and *Pseudomonas radicicola.*

Aerial gonidia and spores: True spores have never been observed. The bodies which Thaxter mentions as possible resting spores have not been observed. He may have mistaken for these bodies the curved ends

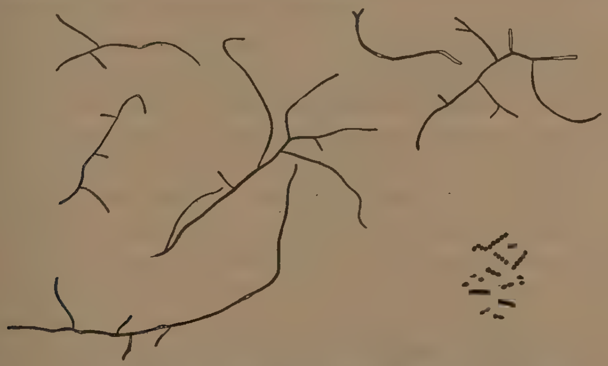


FIGURE 7.—Drawings of the organism *Actinomyces chromogenus* of potato scab, showing the branching and irregular segmentation. Groups of gonidia are shown in lower right hand corner. Magnified about 900 diameters.

and the angles of filaments which, when viewed under the microscope, appear swollen and refractive and resemble resting spores. This appearance has been observed but no true spores have been seen.

A study of a large number of strains shows that some strains or species of this organism produce aerial hyphae and gonidia, as they have been called by some writers; that is, under certain conditions, such as lack of moisture or concentrated medium, the mycelium grows up out of the medium and becomes closely segmented into short rods resembling rod-shaped bacteria. Thaxter (73) writes: "Under certain conditions these filaments may grow up into the air and become spirally coiled at their extremities and subsequently rather closely septate, may break up into short pieces resembling bacteria, at the same time turn-

ing from white to gray." These segments do not have the function or the nature of spores but simply serve as a segment of the mycelium, which by increasing the number of segments may increase the chances for spread and for continuous existence. "This frucification may make its appearance at points on many solid media especially when the latter has become somewhat dry." We have also observed aerial gonidia on some strains growing on milk and various forms of broth, so that we are safe in saying that a lack of moisture is not the only factor controlling the production of these segments.

The formation of aerial gonidia depends to quite a large extent on the strains of the organism; some produce them quite abundantly and in fairly young cultures, while others never produce aerial hyphae or gonidia, or, if so, rarely and under exceptional conditions such as have not obtained here. The original cultures which were first studied, and many other strains now in our possession, have not been known to produce dry aerial growth, with the exception of one strain on a 2 percent lactose agar medium, and it is even doubtful whether or not aerial hyphae were observed at that time. Certainly aerial hyphae or gonidia have not been produced within the last two years while these organisms have been under constant observation on various culture media. On the other hand many strains have been isolated from potato scab, etc., which upon reinoculation quickly produce scab and which show an abundance of the gonidia on practically all common forms of culture media. This is particularly true of three strains, Nos. 150, 151 and 14. The color of this cretaceous surface growth when present varies considerably with different organisms and with the age of growth. With some it is always a pure white or it may be a dark ashy gray; in other cases it may be white at first, gradually turning a dark ashy gray as the culture becomes old. In some other chromogenic species, not known to produce scab, the cretaceous growth may be blue, orange, red, yellow, etc., depending on the species. Repeated inoculations have shown that both the cretaceous and the non-cretaceous strains are capable of producing potato scab and with almost equal virulence. This study of a large number of strains isolated from various sources shows that some produce gonidia more readily than others and that cultures may be selected representing a succession of types from those producing no gonidia through those showing a moderate amount to those producing an abundance of gonidia. Several show gonidia only at a raised point or at the top of the agar slant where the medium is comparatively dry.

These gonidia-like bodies do not resemble spores but they may take the place of true fruiting bodies. They are readily brushed off and broken up and are easily scattered by the wind, or distributed by the soil water. This is an important characteristic since the mycelium generally forms a tough, leathery mass, at least when growing under artificial conditions. The thermal death point is the same as that for the mycelium, contrary to the work of Lachner-Sandoval, Neukirch, Rullmann and others, who claim that these aerial segments show a higher thermal death point than the mycelium. We have found that there is little or no difference between the thermal death point of the mycelium and that of the aerial segments. Further work on this point is desirable.

Capsule or sheath: A capsule or sheath has not been observed, but it is possible that the ends of the filaments may become swollen as commonly found in *Actinomyces bovis.*

Motility: Flagellae are absent and motility was not observed.

Involution forms: No important involutions have been observed, except a greater amount of segmentation and an apparent degeneration of the protoplasm which takes on a granular appearance as shown in figure 7. This granulation of the protoplasm is more readily and more deeply stained than the remaining mycelium.

Staining reactions: The staining of the organisms offer no special features of interest. Preparation from young and old cultures offer similar reactions towards stains with the exception that the staining of older cultures brings out the granular particles more strongly. The organism stains comparatively well with all watery solutions of anilin dyes, carbol-fuchsin and Sterling's gentian violet. It gives a negative reaction to Ziehl-Nielsen's acid-fast stain but a positive reaction to the Gram stain. It is, however, decolorized by prolonged exposure to alcohol.

CULTURAL CHARACTERS

Method of transferring the inoculum: Owing to the tough and coriaceous nature of the group of organisms it is impossible to make transfers by the same methods as are adopted in cultivating the lower or true bacteria, such as by the loop and needle, and secure uniform results. It is impossible to transfer inoculums directly from most cultures by the loop or needle except where aerial gonidia are present. Hence a method which could be used with all cultures was adopted. This consists of transferring a colony or a portion from the culture,

usually an agar stroke culture, to a sterile petri dish and then reducing it to fine particles by mashing with a stiff, heavy (no. 15 gage), flattened platinum needle. This material was then transferred to a tube of sterile water and the inoculations made therefrom by means of sterile pipettes instead of an ordinary loop, one or two drops of the suspension being used. Stab cultures were made with a platinum loop instead of the platinum needle, since the needle seldom carried sufficient to inoculate the medium to any appreciable depth. Even by this method we believe that the inoculations used were not larger than those usually made by the ordinary methods when working with the lower bacteria. Pipettes always took the place of loops and loops always took the place of needles when transferring the finely ground suspension inoculum as prepared above.

Agar stroke: At 25° C. growth appears in 48 hours as visible, straw colored, punctiform colonies, gradually becoming more abundant and spreading over the surface or developing as raised colonies, contoured, rugose to verrucose. All colonies are at first glistening, some strains becoming dull and many becoming cretaceous. The growth is white to straw color and opalescent to opaque; it is thick and tough or coriaceous, requiring a stiff needle to break it up. The medium becomes brown after a few days and gradually diffuses throughout the whole tube. Strain No. 1 never shows cretaceous growth on the surface; No. 14 shows a small quantity after a few days.

Agar plate colonies: Colonies at 25° C. show slow growth, the surface ones developing more rapidly than the deep colonies. The shape at first may be round or irregular depending on the shape and size of the parent particle from which the colony developed. As the colonies grow older they become round, entire, rarely irregular. The surface at first is smooth and lies flat on the medium, later becomes lichenoid, raised, pulvinate or umbonate; in some strains where aerial gonidia are produced concentric rings appear. At times the growth may become undulated and even folded, forming a very much wrinkled colony, the surface ones developing more rapidly than do the deep colonies. The edge is usually entire and filamentous. The internal structure appears amorphous in the denser part of the center, gradually passing to a thinner, filamentous outer edge. See plates V and VI.

The medium becomes brown shortly after growth appears, in from 36 to 48 hours, and continues to increase and spread, discoloring the agar in the neighborhood of the colony until growth ceases. This

browning is of much value in identifying the organism when isolating it from potato scab, soil and other sources. The cretaceous growth in some strains or species appears in from 5 to 10 days, usually in the center of the colony and gradually covering the whole surface, or it may appear as in No. 14 as concentric rings. Cretaceous growth never appeared on No. 1 which is looked upon as the typical organism. The size of the colony varies widely from 2 mm. to as large as 10 to 12 mm., sometimes becoming raised 1 to 2 mm. above the surface of the medium. Some colonies after several days growth crack or break open in various shapes, the crack being in the center and forming a triangle or starlike rupture.

Agar stab: Growth at 25° C. usually appears in 24 to 48 hours, accompanied by browning of the medium. It is abundant and best at the top, very little growth occuring along the line of puncture, as small. white, scattered filamentous colonies. Abundant growth develops on the surface, as a thick, contoured, lichenoid colony or colonies spreading over the whole surface. The growth is straw color. Cultures of Nos. 14, 150 and 151 rarely becomes cretaceous on the surface, No. 1 never. See plate XII.

Gelatin colonies: Plate cultures develop slowly, producing visible colonies in 48 to 72 hours. The colonies resemble those on agar, but are more raised and umbonate, or at times spreading. Liquefaction proceeds very slowly in the neighborhood of the colony, beginning in 5 to 10 days. Aerial growth is seldom secured even with those strains producing aerial segments abundantly on other media. Browning of the medium appears as soon as growth is visible and discolors the medium for a considerable distance from the colony.

Gelatin stab: Growth is best and abundant at the point of inoculation, appearing as a large, spreading, contoured colony. There is little or no growth along the line of inoculation, but when present it is beaded or as scattered filamentous colonies. Liquefaction is saccate to stratiform, beginning in 5 to 6 days and usually complete in from 3 to 4 weeks. Liquefaction progresses slowly and, unless precautions are taken to prevent evaporation, the digested medium evaporates as rapidly as it liquefies, leaving a thick syrupy material in the bottom of the tube. Digestion is accompanied by a deep browning, so that the medium is a very dark brown after a few week's development.

Nutrient broth: Growth is comparatively slow, appearing in 40 to 48 hours as very small compact colonies forming a ring attached to

the glass walls of the tube, as a flocculent suspension, or as a fine, flocculent precipitate. The ring begins to form in 4 or 5 days but may continue to form for a long period, until a complete pellicle is formed. The ring consists of loosely connected filamentous colonies which soon fuse, forming a ring of dense, thick, coriaceous mass, in some cases amounting to a complete pellicle. The ring or pellicle is easily set free from the glass tube by agitation and sinks to the bottom. Some times it becomes free of itself and settles, after which another ring or pellicle may form. Growth may continue to form and then settle to the bottom in this way for several weeks until a large quantity of precipitate has collected. The suspended growths which form beneath the surface of the broth are white, filamentous, ball-like and distinctly nucleate colonies and in some cultures concentric rings may be observed. When resting on any solid substance the growth takes the shape of a hemisphere but is always loose and filamentous. The medium never becomes cloudy, always remaining clear even after several months of growth. From the very beginning of growth a brown stain is produced which discolors the medium, close to the surface at first but gradually diffusing throughout the broth. Very little or no growth takes place in the lower part of the medium, the abundant growth always developing close to the surface. See plate X.

Carbohydrate broths: The influence of various carbohydrates on the rate and nature of growth was studied by making up broths containing 2% of the desired sugar, save that in the case of glycerin 5% was used. Dextrose, sucrose, lactose, manite, maltose and glycerin were used. These substances have but a slight influence on the organism and it seems advisable to record only the fact that the general reactions are not different in essentials from those observed when plain broth is employed.

Yolk of egg: The yellow of six eggs is carefully separated from the white, thoroughly mixed, poured into test tubes to a depth of 1½ inches, placed in the autoclave at a suitable slant and steamed for 10 minutes at 5 pounds pressure. Twenty-four hours after inoculation the egg shows black stains at various points and by 48 hours very dark brown colonies can be seen in the center of the stained areas. The growth continues and by 5 days the surface is covered by a mass of small united colonies, raised and contoured, giving the whole growth a rugose appearance. The egg stains a dull dark brown. No further important characteristics are observed even after

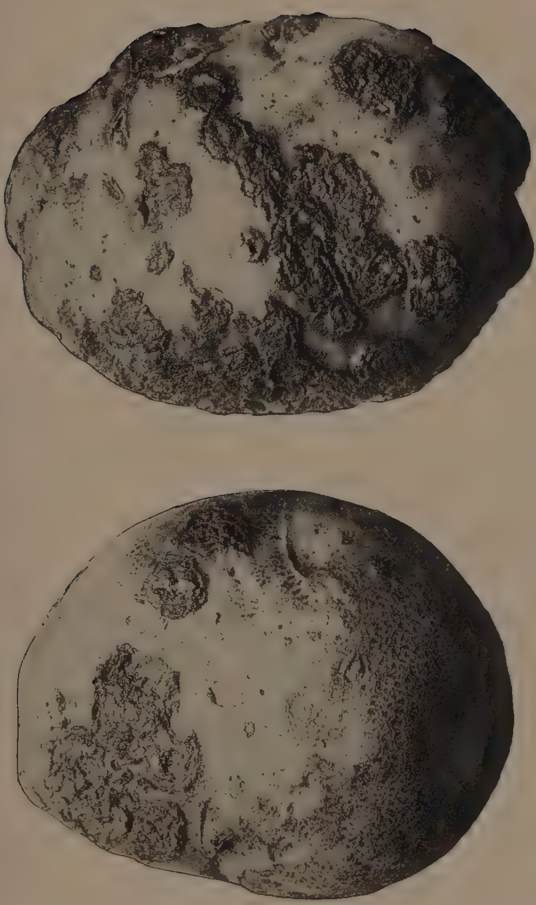


PLATE I.—Potatoes affected by the ordinary scab due to *Actinomyces chromogenus*.

PLATE II.—Potatoes affected by the black or Rhizoctonia scab.

PLATE III. Tuber affected by *Spongospora subterranea*, commonly named "powdery scab." × Scabs unbroken, covered with the epidermis. ° The membranous epidermis lifted up with a pin, showing spore powder. || Two scabs minus the spore powder which form "craters" similar to ordinary scab. (Photo, courtesy of Dr. H. T. Güssow).

PLATE IV.—Whole plant (portion below ground only) of a potato infected with *Chrysophlyctis*, commonly called "potato canker." (Photo, courtesy of Dr. H. T. Güssow).

PLATE V.—Colonies of the four strains of the potato scab organism, *Actinomyces chromogenus*, used in determining the cultural characters.

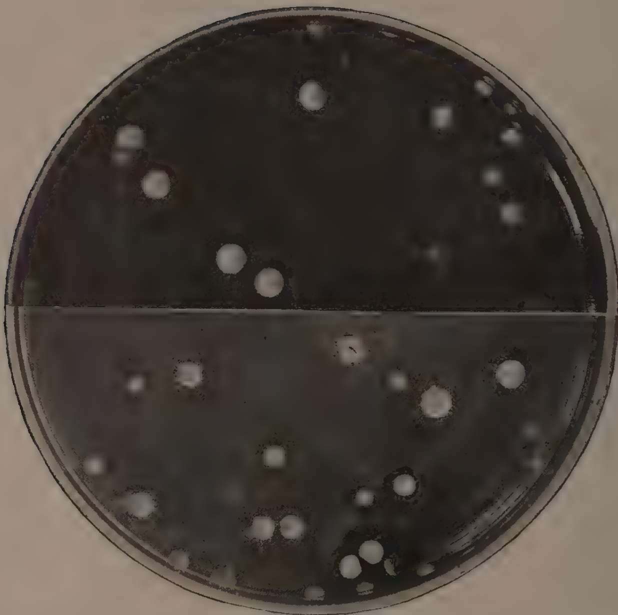


Plate VI.—Colonies of two of the strains of this organism on plain agar. The upper one shows the umbonate appearance which the colonies often show; the lower one shows radial cracking of the colonies.

No. 1. No. 150 No. 151 No. 14

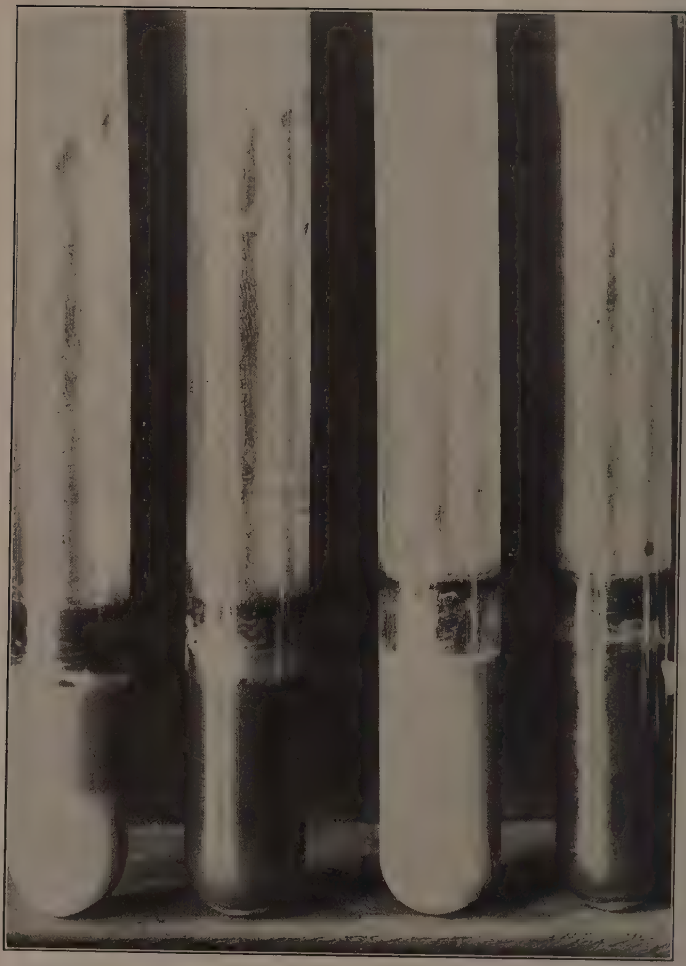
Plate VII.—Cultures of *Actinomyces chromogenus* on potato 2% glucose agar.

No. 1 No. 150 No. 151 No. 14 Check

Plate VIII.—Cultures of *Actinomyces chromogenus* on cooked potato plugs.

No. 1 No. 150 No. 151 No. 14

PLATE IX.—Cultures of *Actinomyces chromogenus* on cooked turnip plugs.



No. 1 No. 150 No. 151 No. 14

PLATE X.—Cultures of *Actinomyces chromogenus* on maltose broth.

No. 1 No. 150 No. 151 No. 14

PLATE XI.—Cultures of *Actinomyces chromogenus* on plain milk.

PLATE XII.—Growth of *Actinomyces chromogenus*, Nos. 1, 150, 151 and 14 in plain agar stabs, incubated at 25° C. for 10 days, showing nature of growth along the line of puncture and the elevation of surface colonies.

the cultures have been kept for several weeks. Nos. 150 and 151 produce a small quantity of cretaceous growth after 5 days.

Egg albumen: The white of six eggs is distributed among a number of test tubes, slanted and autoclaved for 10 minutes at 5 pounds pressure. These slants are not smooth, as large and irregular cavities in the medium are formed by escaping air. The growth is very slow, after 48 hours appearing as a brown smear, in 5 days spreading and becoming coriaceous, glistening and dark brown, the medium becoming a very dark brown. No further changes are noted. The organism does not develop very rapidly on this medium.

Blood serum: Blood serum slants are made by sterilizing blood serum in the autoclave at 5 pounds for 10 minutes. The growth is very slow. The medium in 24 hours becomes a dark brown but no growth is observed until after 5 to 10 days. No. 14 alone shows small, effuse, brown colonies after 5 days. Growth is indicated, however, by the browning of the medium.

Blood serum broth: The growth is slow, none appearing before 3 days. At the end of 5 days growth appears as a straw-colored ring composed of small, flocculent filamentous colonies suspended at the surface. The broth is browned and clarified to a depth of 25 to 30 mm. No. 151 gives better growth in this medium than any other strain; No. 14 gives very little growth.

The growth of these organisms is very slow on either coagulated blood serum slants or in the broth. This may have been due to the nature of this special lot of serum, or it may be that the organism does not find in blood serum a suitable medium.

Potato glucose agar strokes: 250 grams of potatoes are sliced and boiled in 500 cc. of distilled water for 30 minutes, the water filtered off and made up to 500 cc., 1% agar and 2% glucose added, the agar being dissolved by steaming, autoclaved at 10 pounds for 10 minutes, filtered, tubed and sterilized at 10 pounds pressure for 10 minutes.

The growth appears in 48 hours as punctiform, straw-colored colonies. By 72 hours the medium begins to show browning and by 96 hours the browning is quite marked, having penetrated to a depth of 5 to 6 mm. The growth generally consists of a large number of colonies ranging from barely visible or punctiform to colonies, 2 mm. in diameter, slightly raised and straw-colored. It was noted that the growth does not appear on the agar covered with the water of condensation at the bottom of the slant, possibly because of its strong

anaerobic characters. The growth continues and by 7 days may have spread or united, giving the appearance of a smear beset with papillae. Browning has materially increased, the medium being a dark brown to a depth of 8 to 10 mm., and in the course of 10 days it becomes almost black. After 16 days the growth may be described as forming a heavy, thick, coriaceous, papillate, much wrinkled coating over the whole surface. Very often the papillae crack, leaving an irregular triangular or star-shaped opening in the center of the colony. For 23 days the growth continues to increase and to become more wrinkled and contoured, resembling the inside of a chicken's gizzard, and more of the papillae burst or crack open. Between 23 and 42 days there is little or no increase in growth and practically no change in appearance. The following description may be given: Growth, slate color at top and grading into a dark straw color at the bottom, glistening and semi-translucent; growth abundant, raised, spreading, wrinkled papillate and rugose. These cultures were kept for 10 weeks without further change. See plate VII.

Cultures of Nos. 14, 150 and 151 afford an entirely different appearance on this medium. All cultures are almost identical for 4 days but after that time slight differences appear. The colonies of these organisms are larger and more irregular than those of No. 1. Cretaceous growth appears on Nos. 150 and 151 in 7 days and completely covers the growth in 23 days, while No. 14 does not become cretaceous until it is much older. Browning of the medium is decidedly more intense in the case of Nos. 150 and 151; otherwise there are only minor differences of little importance. Growth is more abundant on this medium and the browning more extensive than on any other medium, except potato peptone glucose agar. It is also more suitable as a means of bringing out the peculiar characteristics of the organism than are the more common media.

Potato peptone glucose agar: This medium is made in exactly the same manner as potato glucose agar with the exception that 1% peptone is added. After 48 hours a light straw-colored growth is apparent, accompanied by slight browning of the medium. After 72 hours growth is abundant, consisting of a rugose smear containing many papillae, possibly the foci of original colonies, accompanied by a dark brown staining of the medium. By 96 hours the medium is still more deeply stained to a depth of 10 mm. The growth continues to increase and to form a tough, thick, coriaceous layer. By 7 days the growth has increased materially, the brown staining extending into

the medium 15 to 20 mm. By 10 days the growth is still more wrinkled. After 16 days the growth may be described as abundant, thick, leathery, papillate, verrucose and of a straw-brown color. There is a peculiar pocket and apron form of growth developed, due to the shrinkage of the medium at the bottom of the slant. A thick growth develops over the whole surface and the edges adhere to the walls of the tube, the medium shrinks with age and draws away from the glass at the lower edge of the slant, and the growth now develops on this new surface forming the apron, the pocket being formed just above this. No further change is noted after 10 weeks.

Nos. 150, 151 and 14 show a different appearance on this medium after 16 days, but not more marked than on the potato glucose agar. The growth of these three organisms on this medium seems more abundant and accompanied by a more cretaceous surface than that on any other medium. Browning is also more marked, a very deep brown color being manifested but not the black-brown tinge observed in the potato glucose agar.

Potato plugs cooked: After 48 hours growth appears as an effuse, papillate smear over the entire surface of the potato, accompanied by slight discoloration. After 96 hours growth materially increases, becoming verrucose, contoured and wrinkled. The color of the growth and potato is a muddy gray but not brown. The growth continues to increase from day to day, by 20 days being very abundant, consisting of a single, tough, thick, contoured and very much wrinkled mat or lichenoid colony spreading over the entire surface, glistening and of a gray opalescent or slightly straw color. The potato is colored dark gray. No further change appeared, although the cultures were kept for over 6 weeks. Nos. 150 and 151 act much as does No. 1, except that slightly more vigorous growth and darker discoloration appears, and that after 10 days the surface is completely covered with an ashy-gray aerial growth.

Turnip plugs cooked: No growth appears within 48 hours. After 4 days, a slight growth of small, raised, opalescent colonies 1 to 2 mm. in diameter is manifested, but no browning. After 8 days, an abundant growth of crowded colonies occurs, giving the surface a wrinkled, umbonate, umbilicate and verrucose appearance. The growth is white and opaque, a few colonies in one series showing a slight tint of orange. By 20 days, the growth materially increases, still retaining, however, the appearance manifested at 8 days. The color of the organism in

mass on the turnips is very interesting and seems to vary with the different strains. No. 1 displays a rich cream hue with an outer edge of light cream; No. 151 resembles in structure and form No. 1, but manifests a greenish-gray color, the turnip sometimes browning; No. 150 is verrucose and cretaceous after 20 days, accompanied by distinct browning of the turnip. The growth of No. 14 is contoured, effuse, raised, translucent, the turnip being only slightly discolored. Turnip plugs seem to be a suitable medium for bringing out these differences in cultural characters. See plate IX.

Carrot plugs cooked: No growth occurs within 48 hours. After 96 hours, small, raised, opalescent colonies 1 to 2 mm. in diameter ap-appear. After 8 days, abundant, verrucose colonies, raised and umbilicate, opalescent and semi-transparent, glistening and dull, are observed. By 20 days the growth is abundant, spreading, raised, contoured and wrinkled, straw-colored and opalescent, and the carrot is slightly discolored. After 8 days, colonies of No. 150 show a slightly wrinkled surface, partly covered with a gray, cretaceous growth. After 20 days, the surface is very rough and covered with cretaceous growth. No. 151 affords the most abundant growth, verrucose and contoured, with a gray, cretaceous surface around the edge of the colonies. No. 14 grows poorly on carrot, after 20 days showing only moderate or scanty growth, spreading and as individual colonies, effuse, and umbonate, sometimes distinctly raised and contoured, translucent and opalescent. The carrot is slightly discolored. These four strains show quite a difference in minor respects on this medium. Carrot plugs appear to bring out the differential characters quite markedly.

Beet plugs cooked: Very little growth appears within 48 hours, but in 96 hours the growth becomes fairly abundant, as small, raised, opalescent colonies and the beet is discolored. After 8 days, an abundant growth occurs of verrucose and very decidedly capitate colonies from 1 to 2 mm. in diameter, and the beet is markedly discolored. After 20 days, an abundance of a peculiar colonial-like spreading growth, contoured and overlapping, vissiculate to bullate, and dark straw-colored to opalescent, is observed. The growth is abundant with all four strains except No. 14, wherein it is moderate or scanty and effuse. Nos. 150 and 151 appear creamy and opaque, while No. 1 is opalescent and semi-transparent. No. 151 shows a marked umbilicated form of growth, while No. 150 displays a slight quantity of cretaceous surface. Beet plugs are also valuable in indicating cultural differences among these organisms.

Plain milk: There is only slight growth manifested and no change occurs in the milk within 4 days. By 8 days, however, the growth assumes a brownish-white ring formation, and the milk turns a brownish-cream color. By 20 days, a heavy, thick, contoured ring forms and the milk is a whitish-gray throughout, with a slight tinge of brown. In 30 days very little change occurs, with the exception of an increase in growth and a progressive discoloration of the milk until it assumes a greenish-brown color. Nos. 150 and 151 resemble No. 1 quite closely, except that growth seems more vigorous and the characteristics more pronounced in the former than in the latter. No. 14 shows wide variation from the other strains. The growth is more rapid and is accompanied by digestion of the milk within 96 hours to a depth of 3 to 5 mm., the balance of the milk becoming brownish-white. The milk is completely digested within 15 days, gradually becoming translucent, leaving a dark brown semi-transparent serum. Ring and pellicle formation is sometimes accompanied by digestion, but not in all cases.

Litmus milk: After 48 hours, the growth is indicated by an intensifying of the blue to a depth of 10 to 14 mm., indicating the production of an alkali, accompanied by slight surface growth. By 72 hours, the growth assumes a pellicle formation, accompanied by the deepening of the blue coloration which now extends much further into the milk. By 4 days, the upper 5 to 10 mm. changes to a tea-blue color, possibly a combination of the brown pigment and the litmus. The growth forms a very compact, contoured, wrinkled pellicle over the entire surface. The change in color of the milk does not extend to a depth of more than 25 mm. After 7 days, the above characters are intensified, the pellicle gradually becoming tougher and thicker. The milk shows zonation of different tints of brown-blue to the original litmus blue of the milk, the number and shades of the zones varying with the age of the culture as well as with the strain of the culture. By 16 days the milk displays partial digestion with a blue or black color by reflected light and a reddish-brown by transmitted light. The milk is never completely clear, but nevertheless the casein becomes partially dissolved. Nos. 150 and 151 are more active in discoloring the milk than is No. 1 and the pellicle formed with these strains shows a slight amount of cretaceous surface. No. 14 shows a change from an alkali to an acid reaction after 13 days. By 23 days the casein is digested and clarified to a depth of 30 mm., and the digestion is complete within 45 days with further indications of acid production. No. 151 also has shown the production of acid in one series of tests.

BIOCHEMICAL CHARACTERS

Indol production: The tests for indol are conducted in sugar-free broth made from Liebig's meat extract, inoculated with the desired organism and incubated at 25° C., and for periods of 5, 15 and 35 days. The test is made by adding 10 drops of sulphuric acid and 1 cc. of a 0.02 percent sodium nitrite solution to approximately 10 cc. of the culture. Indol is rarely and sparingly produced in sugar-free broth. The cultures were under observation for 35 days, and numerous tests made beside the regular ones at intervals of 5, 15 and 35 days. Nos. 150 and 151 and 14 never afforded indol reactions, while No. 1 gave a slight reaction after 15 days in one series.

Ammonification: Two hundred cc. of nutrient broth in 500 cc. flask were heavily inoculated with finely broken particles of the culture of the organism and incubated at 25° C. Ammonia determinations were made after periods of 14 and 30 days, using 50 cc. of the culture. 50 cc. of water and 2.5 grams of magnesium oxid. The usual chemical procedure for the determination of ammonia was carried out, controls being made with results as follows:

AMMONIA PRODUCTION IN NUTRIENT BROTH

Number and name of strain	Ammonia produced: equivalent to cc. of N/10 HCl per liter. in 14 days	in 30 days
No. I	8	7
No. II	10	9
No. 150	14	16
No. 151	12	8.7
No. 14	7.5	..
Control flasks	0.5	0.6

These figures are small as compared with those yielded by most other bacteria under similar circumstances. This outcome seems counter to the general impression that organisms of the Actinomyces (Streptothrix) type are strong ammonia producers.

Acid production: Acid tests were made in plain nutrient broth and in broths containing dextrose, sucrose, lactose, manite and maltose, each 2 percent, and glycerine, 5 percent. Sixty cc. of the broth in 100 cc. flask were inoculated and incubated at 25° C. After periods of 5, 15 and 30 days the cultures were titrated against N/20 NaOH, using phenolphthalein as an indicator, with results as follows:

Plain broth	Cc. of acid produced equivalent to cc. of N/1 NaOH per liter: in 5 days	in 15 days	in 35 days
I	13.5	14.25	12.0
150	13.5	14.5	14.5
151	13.0	13.25	12.75
14	13.5	14.85	12.75
Control	13.5	12.1	....
Plain broth plus 5% glycerin			
I	10.75	...	13.3
150	10.75	...	13.5
151	10.95	...	14.25
14	13.0	10.5	14.0
Plain broth plus 2% dextrose			
I	1.20	....	17.2
150	11.5	....	14.7
151	12.0	....	...
14	16.25	17.25	18.4
Plain broth plus 2% sucrose			
I	11.5	....	15.2
150	10.9	....	12.75
151	10.6	....	13.75
14	14.0	14.5	16.4
Plain broth plus 2% maltose			
I	14.25	....	17.55
150	14.1	....	18.0
151	13.65	....	13.5
14	18.5	25.25	20.9
Plain broth plus 2% lactose			
I	12.5	....	16.65
150	12.15	....	17.85
151	11.25	....	14.75
14	16.0	15.25	18.0
Plain broth plus 2% manite			
I	10.75	....	15.25
150	10.25	....	13.1
151	10.5	....	14.5
14	14.0	14.1	...

Gas production: Fermentation tubes containing plain broth and broth with either 5 percent of glycerin or 2 percent of one of the following sugars, dextrose, sucrose, maltose, lactose or manite, received heavy inoculums of the various strains, and were incubated for 5 weeks at 25° C. and at room temperature (22.5° C.) for 5 weeks longer. Gas is not formed in any carbohydrate medium tested; neither have any characteristics been observed which would indicate that the organisms are able to produce gas under any circumstances.

Browning of the medium: Many organisms of the potato scab group have the power of producing a brown pigment which is soluble and diffuses through the medium in the vicinity of the colony. This browning is more or less marked in all strains known to produce potato scab. Other strains isolated from the soil do not produce browning of the medium, but some produce a blue stain, others a yellow, orange or red pigment, and all the stains seem to be diffusible throughout the medium. Claypole (12) divides the pigment into two groups, one brown and diffusible, the other yellow, pink, or bright orange and not diffusible. At least the pink and blue pigments of these organisms are capable of diffusing through the medium. Beijerinck (3) observed the brown coloration of culture medium in cultures of Streptothrices, particularly *Actinomyces chromogenus*. He supposed this pigment to be chinon and gave tests for it. Several attempts to confirm his results by applying his methods and tests have failed. We have not identified the brown pigment and the question as to its chemical nature must be through the medium."

While it is comparatively easy to show the relation of this organism to the thread bacteria, as was pointed out in 1911, it is a much more difficult problem to decide on the generic name which should be accepted for this group. The following are the generic characters recognized as characteristics of this group, whether called *Streptothrix, Actinomyces,* or one of the other numerous generic designations. "Cells either short or long, cylindrical, clavate, cuneate in form, which at times may show true branching, or long branched mycelial-like filaments, not surrounded by a sheath, without endospores but with the formation of conidia-like bodies, due to the segmentation of the cells. Division at right angles to the axis of the rod or filaments; cultures usually may or may not have a moldy appearance due to the development of aerial hyphae; growth may be accompanied by the production of a brown, pink to orange or blue pigment which may or may not diffuse considered as still unsettled.

The characters of the potato scab organism readily show that it belongs to this group. This is also confirmed by a parallel study of cultures of this organism and other organisms known to be members of this group which have been secured from various sources.

In determining the generic name for this group of bacteria reference has been made to the works of numerous authors. Among the more important are: Meyen, 1827; Corda, 1839; Cohn, 1875; Harz, 1877-78; Lehmann and Neumann, 1899; Migula, 1897 and 1900;

Chester, 1901; and Gasperini, Saccardo and others, 1891. Three of the more important recognized determinative manuals of bacteriology agree as to practically the same characters for this group, but accept a different generic designation. This is due to the fact that the founders of the different genera were not careful in selecting names which had not previously been used to designate other fungi. The following are the three generic names which are most commonly used in the different works on classification.

Chlamydothrix, Migula (Migula).

Streptothrix, Cohn (Chester).

Actinomyces, Meyen, Harz (Lehmann and Neumann).

Chlamydothrix: Migula does not recognize a genus to which this organism may correctly be referred, unless it be placed in the family *Chlamydobacteriaceae* and genus *Chlamydothrix* Migula. This genus is characterised by unbranched filaments surrounded by a sheath, characters which are quite sufficient to exclude this group of organisms.

Streptothrix, Cohn: Chester (11) recognizes the genus *Streptothrix* of Cohn and considers the genus *Actinomyces* of Harz to be a synonym. Cohn (14) described these organisms in 1875 and applied the generic designation *Streptothrix,* founding it on the species *Foersteri.* Cohn failed to recognize that Corda had described in 1839 two fungi belonging to and still retained in the family *Dematiaceae* to which he gave the generic name *Streptothrix* and the species names of *S. fusca* and *S. brune.* Engler and Prantl (18) as well as Saccardo (59) recognize Corda's genus and mention that there are 5 species, among them being *S. fusca,* Corda and *S. cinerea,* Morg. His plate clearly indicates that his organisms did not resemble the thread bacteria, as their reproductive bodies are conidia, borne terminally and in the axils of branches.

Since Corda's genus and species are recognized fungi of the *Dematiaceae,* it naturally follows that the application by Cohn of the same name to the thread bacteria which are closely related to the true fungi was a mistake and that Cohn's genus *Streptothrix* must be dropped.

Actinomyces: Lehmann and Neumann (44) recognize the genus *Actinomyces* of Harz (1877-78) as the correct name for this group of organisms. In 1877-78 Harz described the organism of lumpy jaw or actinomycosis and gave to it the name *Actinomyces bovis,* which it still bears. He, however, failed to note that Meyen described in 1827 an organism growing on a piece of fat meat in a pond of water which

he called *Actinomyce horkelii.* This organism of Meyen does not seem to have been recognized by others, and in all probability it was one of the numerous water molds which grow readily on animal tissue. Since the generic name *Actinomyce* as given by Meyen does not indicate anything definite and has fallen into disuse, there seems to be no reason why its application by Harz to a specific organism should not be recognized, particularly as it has already become firmly established and its priority does not seem to be questioned.

Species: The organism which causes the potato scab, at least many of the strains, resembles in practically every detail *Actinomyces chromogenus,* Gasperini (24) 1891, which, according to Lachner-Sandoval, is synonymous with *Streptothrix nigra* of Rossi-Doria (57) 1891; at least the main characters are identical, with the one exception that all strains do not produce a cretaceous surface growth with aerial conidia. The following is Chester's characterization:

STREPTOTHRIX CHROMOGENA GASPERINI

Morphology. Branched filaments, often evidently septate, composed of long and short elements. In the aerial hyphae by segmentation short coccoid gonidia. Stain by Gram's method. Grow at 20°, but best at 37° C. Aerobic.

Gelatin colonies. Round, slightly raised, brownish, but with a whitish dry chalky appearance in the centre, becoming concentric. Gelatin around the colony dark brown and slowly liquefied, leaving a chalky crust on the surface of the liquefied gelatin. Microscopically, filamentous, tangled, becoming opaque in the centre with a filamentous border.

Gelatin stab. In depth, short radiate bundle-like outgrowths after some time; on the surface like gelatin colonies, gelatin slowly liquefied beneath.

Agar stab. In depth, bristly outgrowths; on the surface, growth moist, yellowish, glistening, raised, becoming dry, warty; agar stained a deep brown.

Agar slant. Growth brownish, slightly spreading, becoming whitish, chalky.

Bouillon. On the surface, a delicate and, later, a tough membrane.

Glucose bouillon. Radiate masses at the bottom; medium, brownish.

Milk. A tough, yellowish-brown growth on the surface; medium rendered alkaline and peptonized.

Potato. Growth yellowish to yellowish-brown, becoming chalky. The medium is stained a deep brown or black. The culture has an intense moldy odor.

Habitat. Air, water, and stomach contents.

A comparison of the above characteristics with those of our organism will leave no doubt that they are one and the same thing and that the writers are justified in changing the name of *Oospora scabies* Thaxter to *Actinomyces chromogenus* Gasperini. The latter organism has been repeatedly isolated and described, although not always under this name.

Cladothrix dichotoma Cohn has a sheath according to the original description, but the cultural characters as given by Macé (46) are

identical with those of *A. chromogenus.* It is entirely possible that some of the authors who described their cultures of this species had *A. chromogenus* instead.

Krüger (41) claimed that his *Oospora nigrificans,* isolated from girdle scab of the beet, is distinct from *A. chromogenus;* but they agree fairly closely in their cultural characters and are probably nearly related.

Rullmann (58) found and described under the name of *Cladothrix odorifera* an organism that is of particular interest in the present discussion. The author, investigating the soil under two houses in which a typhoid fever epidemic had occurred, isolated an organism which, in culture, produced the peculiar earthy odor of garden soil. The polluted soil full of organic matter common around houses offered a favorable substratum for the growth of this fungus and always contained it. This organism, as afterward admitted by Rullman, is identical with *Actinomyces chromogenus.*

Beijerinck (3) found *Actinomyces chromogenus* to be one of the widest spread organisms in garden soil, where it was common at a depth of one metre. In sand it was found two metres below the surface and in alluvial mud, three metres. It was also common in river water and was especially abundant in and close to plant roots of various sorts. The parasitism of the organism was doubted by Beijerinck, but it must be pointed out that he gives no account of having tested the pathogenicity of the organism on either the potato or beet.

It must be said further that giving the organism the name *Actinomyces chromogenus* and indicating its almost universal occurrence, does not preclude the possibility that inside the species there are various strains, some of which are more strongly pathogenic on potato tubers and on beet roots than others. With some strains it may be necessary that the chemical and physical soil conditions be exactly right if the organism is to attack these plants successfully, while with others the surroundings may not need to be as favorable. Some of our cultures have been kept for 5 years and still retain their virulence, so that this character is not one that is readily lost under artificial conditions. The culture of *A. chromogenus* obtained from Kral's laboratory, while it differs in certain characteristics from the published descriptions and from our cultures of the potato scab organism, was found to produce scab in some cases.

Güssow (27) has proposed not only the name *Actinomyces scabies* for the scab organism, but that all the thread bacteria given in

Saccardo under the generic name *Streptothrix* should be called *Actinomyces*. The potato scab fungus, as is shown in this bulletin, has already been described and named by Gasperini in 1891 as *Actinomyces chromogenus,* and the changing of the generic name *Streptothrix* to *Actinomyces* has already been made by Gasperini, Lachner, Sandoval, Neukirch and others.

SPREAD OF THE ORGANISM

The utilization of scabby potatoes as seed has been supposed to be the principal means by which the scab organism finds its way into soil previously free from it. Undoubtedly scabby seed tubers offer an especially favorable chance for the infection of the succeeding crop. The organisms are present in the old scabs in the greatest abundance and are located in the exact region where the new tubers will be formed. The presence of humus or dung and of the remains of the body of the old tuber offer a favorable culture medium for the increase of the organisms in the hills. Manure is an almost unrecognized danger in the spread of the organism. Thaxter (74) has shown that it grows abundantly in an infusion of horse dung and the inference naturally follows that it will also multiply abundantly in the manure itself. *Oospora perpusilla,* a closely related species which, however, is not known to produce scab, has its natural habitat in manure.

In view of these facts two common farm practices are particularily to be decried as likely to result in a wholesale seeding of the farm with scab organisms, viz.: (1) dumping diseased and scabby potatoes on the manure heap and (2) feeding scabby tubers to farm stock. Morse (51) has shown that potato scab organisms survive the passage through the digestive tracts of the horse and cow and reinfect potato tubers with which the dung comes into contact. A mature horse and cow were fed scabby potatoes, the excrement collected, and added to sterile soil in which potatoes were planted with the following results:

SCABBING OF TUBERS DUE TO INFECTED MANURE
(Maine Exp. Sta., 1912)

	Total number of tubers	Number of tubers not scabbed	Percentage of scabbed tubers
Horse	61	45	26
Cow	91	91	0
Check	16	16	0
Horse	50	12	76
Cow	65	54	17
Check	17	17	0

Halsted (31) had already shown that the addition to the soil of scabby potatoes or of manure from animals that had been fed scabby potatoes would increase the amount of scab from three to five fold. Steaming the scabby tubers for 20 minutes did not seem to lessen materially the proportion of scab in the preceding crop. The passage of the organism through the digestive tract of a heifer seemed more seriously to affect the vitality than did the passage through that of a mature animal.

The organism seems not only to survive but to grow in the soil if the right conditions are provided. A case of such long persistence has been observed by one of the writers on a piece of land with the history of which he is familiar. A part of a field had been a woodyard; its soil was full of organic matter but had borne no crop for over 40 years; yet potatoes planted after the old woodyard had been plowed produced so scabby a crop that it was unsalable. Other instances of this nature might be cited.

Sorauer (64) tested the ease with which scab could be conveyed to land that was free from it by planting scabby seed. The harvest was almost clean and his conclusion was that unless the soil was inclined to favor the scab very little of the disease would appear and that the means for control must be directed toward changing the soil conditions. It will be observed that no checks were planted with manure which had been sterilized or added to ordinary unsterilized soil in any of these experiments on the spread of the organism in that substance.

The fact that the present discussion does not derive its importance from a mere change in nomenclature of the scab organism must be still further emphasized. The cultural characters indicate definitely that the organism with which we are dealing in potato scab is a widespread, normal soil inhabitant, occurring in cultivated soils, probably everywhere. Fousek (19) found that of the total number of organisms occurring in a loam soil in Austria 20 to 30 percent were *Actinomyces albus* and *A. chromogenus*, that in a clay soil from 8 to 15 percent and that in a sandy soil from 7 to 10 percent were of the same sort, and, furthermore and important, that these organisms were abundant on the roots of many plants as well as on decaying plant debris. He further found them able to decompose peptone, blood, bone meal and straw, and to use cellulose as a source of carbon. In fact, they serve as one of the most rapid decomposers of organic matter in the soil and have a favorable effect upon the growth of certain plants.

Beijerinck (3) has found that they occur in great abundance on the roots of almost all sorts of plants, including oaks, beeches, hazelnuts, elms, alders and various ferns, and that they are also found in the soil near the roots.

Potato tubers grown in the station greenhouse in the spring of 1914 were badly infected with scab. The soil was a mixture of clay, sand and well rotted manure and had been in the benches all winter. During the growing period of the potatoes it was kept very moist. Soil was taken from various places in the beds, gram samples weighed out, dilutions made in 100 cc. water blanks without previous grinding and plates poured from plain agar from dilutions of 100,000 and 500,-000. The *Actinomyces* colonies were large enough to count after 9 days. The following table shows the number per gram in the various soils.

BACTERIA IN ONE GRAM OF GREENHOUSE SOIL; COUNTS MADE ON AGAR PLATES AFTER 9 DAYS

Bench	Total number of organisms	Actinomyces albus[1]	Actinomyces albus, percent	Actinomyces chromogenus	Actinomyces chromogenus, percent
I	2,170,000	30,000	1	0	0
II	2,190,000	400,000	18	425,000	19
III	2,590,000	580,000	22	650,000	25
IV	2,090,000	380,000	18	125,000	6
V	1,630,000	260,000	16	170,000	10
Averages	2,134,000	350,000	15	274,000	12

A certain market garden plot near Burlington produced a very high percentage of scabby beets in 1913. On April 27, 1914, soil samples taken from depths of 3, 6 and 9 inches were plated out as in the preceding experiment. The counts made on May 6, after 9 days incubation at room temperature, were as follows:

Total number of organisms	Actinomyces albus	Actinomyces albus, percent	Actinomyces chromogenus	Actinomyces chromogenus, percent
1,930,000	207,000	10.7	466,000	24.1

Twenty-seven percent of the organisms in the greenhouse and 35 percent of those in the garden soil were *Actinomyces* of one or the other species. It is not always easy to differentiate between *Actinomyces chromogenus* and the so-called *A. albus*. There is considerable variation even in the former in the amount of coloring matter produced, and unless the medium is stained sufficiently, so as to be

[1]The A. albus may include other organisms and may be the same as A. graminarium.

readily recognizable, the colony might be counted as *A. albus*. The latter species has never produced scab with us. With approximately 274,000 units of *A. chromogenus* in every gram of the greenhouse soil under examination and approximately 466,000 in every gram from the garden soil, it would seem difficult for any potato tuber grown thereon to escape serious infection. There is always the possibility, however, that special conditions are necessary for infection and that some strains of this organism will produce scab much more readily than others. Inoculation trials with a number of strains of the chromogenus type seem to indicate clearly, however, that those forms with well marked characters, especially the ability to darken the media, will readily produce scab when brought into contact with a growing potato tuber.

Bolley's recent bulletin (7) on the deterioriation of wheat caused by the attacks of fungi on the roots and stems of the plants, is of special importance in connection with these studies on scab. Some of his recommendations for the control of such soil fungi are particularily pertinent, especially that seed wheat should be disinfected and that the manure containing old wheat straw should not be applied directly to wheat land, but should either be rotted or be put on the land before growing other crops not related to wheat. The results herein reported on the scab organism would indicate that any such procedure would probably increase its numbers and virulence. Bolley expresses considerable faith in the rotation of crops in the control of corky scab, and it is undoubtedly true that the continued growth of potatoes on the same land increases the percentage of affected tubers. Clinton (13) found on a piece of land under his observation that in 1906 the amount of scabbing was below 5 percent, and probably not over 1 percent. The second year the proportion of scabby tubers had increased to 22 percent, in 1908 to 47 percent (the same potatoes in our general rotation fields this year were only about 1 percent scabby) and in 1909 to 63 percent. No statement is made as to the treatment of the field further than that half of it was manured each time and that the scabbing was worse on this part of the field than it was on the remaining half which only received nitrate of soda. The alternation of other crops, such as grass, oats or corn with potatoes, would seem to be highly desirable since the scab organism does not find that the conditions that are best for the growth of these crops are likewise best adapted to its own increase. In fact such periods may be regarded as starvation times for it, times in

which the weaker individuals die off. In garden soil that is always kept rich with humus it is doubtful if any such change of crops would naturally affect the numbers of the organism, for enough humus would always remain in the soil for it to survive in abundance until another crop of potatoes was planted. The indefinite continuation of scab in rich garden soils is a matter that can be confirmed in any part of the country, and no investigator has yet dared to put an estimate upon the length of time which it remains active.

The question of the advisability and effectiveness of the disinfection of seed tubers comes prominently to the front if the statements as to the nomenclature and widespread occurrence of the organism presented in this bulletin are correct. It is doubtful if there is any rich garden soil in which it cannot be found in abundance; indeed the characteristic earthy odor usually found in such soils is one of its products, and Rullmann (58) has made a new species of this organism, *Actinomyces odorifera,* because of this peculiar property.

At the present time it is difficult to find land in the older regions of this country, such as New England, upon which potatoes have not been grown, or into which the organism has not been transferred in some manner. There are all sorts of opportunities for the infection of soil by an organism which can be carried so easily and which lives readily there as a normal inhabitant. It is highly probable that it has always been present in rich soil and that no inoculation by human hands is necessary to introduce it. The thread bacteria of this group undoubtedly play an important role in the chemical changes which some of the ammonia compounds undergo, and in the process receive a large share of their energy. The practicability of seed potato disinfection is therefore questionable. Although it is true that experiment station bulletins without exception recommend it, a study of the work that has been done along the line of seed tuber disinfection will show that no claim for its value is made if the soil is already infected. The chemical reaction and the moisture content of the soil are of much more importance than is tuber disinfection. If the soil is quite alkaline in its reaction and is very moist, a bad crop of scabbed potatoes will almost inevitably result. Future experiments looking towards the prevention of potato scab ought, therefore, to be considered along one of two lines; viz. (1) killing the organism in the soil, or at least preventing its growth; (2) correcting soil conditions, i. e. excessive alkalinity and moisture, so that these thread bacteria will not grow as rapidly.

The writers recommend, therefore, in the disinfection of badly scabbed tubers, to use either formaldehyde or corrosive sublimate. The tubers may be soaked for two hours in a solution of a pint of the commercial formaldehyde in 30 gallons of water, or for the same length of time in a solution of one ounce of corrosive sublimate to 15 gallons of water. Of course badly infected seed tubers should not be planted if others can be had, as their germination is always somewhat inferior, but if no others are available they may be used after disinfection. The decaying mother tuber furnishes an admirable growing place for the *Actinomyces* in that portion of the soil where new tubers are to be formed. This condition of affairs is aggravated if any quantity of manure or humus is in the soil and the chemical reaction is alkaline. If scabbing of the seed tubers is only occasional and the spots are small, but little gains are to be derived from seed disinfection. Not only is the benefit slight, but there is always the chance of injuring the seed to some extent even though the operation is carefully done. Stewart and Gloyer (65) have shown that tubers disinfected by formaldehyde or strong corrosive sublimate solutions may develop sunken brown spots surrounding the lenticles and eyes. Tubers that have sprouted are especially susceptible to injury around the eyes. This would overcome the small benefit derived from this practice.

SCAB PREVENTION

Three methods of scab prevention have been recommended by various workers. These have been under observation almost constantly since the malady has been the subject of scientific investigation. They are: (1) fungicidal treatment; (2) the application of reputed retarders to the soil; (3) crop rotation. Though aiming at the same goal their methods are widely different in practice and application. Disinfection seeks to remove the organism from the seed tubers before planting; soil treatment aims at destroying the organism or rendering it inactive through the use of some deterent soil amendment; and the supposed efficacy of crop rotation is based upon the assumption that if potatoes or other susceptible crops are not grown continuously on the same soil the organism will ultimately die out or be so diminished in numbers as to be capable of being held in check. The means by which the results were obtained were not at first fully understood, since it was contended that the disease was not caused by living organisms but by lifeless soil substances, physical or chemical in nature. Nevertheless, research led to the conclusion that certain fungicidal treat-

ments tended to reduce scab and under well controlled conditions to prevent it entirely.

During the summers of 1912 and 1913, a series of trials were conducted at Burlington with a view of studying the influence of certain materials on the scabbing of potatoes in this section of the country. It was not the intention of the writers to test any new chemical method of control, as almost every substance that might be a possible preventive has been used in experimental trials. The results obtained, at various locations, however, have not been always in agreement and it was felt that the importance of the work made a repetition desirable under Vermont conditions. The 1912 tests were made on a heavily manured, light sandy soil which had been in grass for several years but was in a good state of cultivation. The potatoes, with the exception of those planted in the drills with fresh lime and manure, were planted by a potato planter. Where manure and lime were used, the tubers were plowed in and the manure or lime scattered in on top of the seed. The 1913 tests were made on a rich, heavy clay loam which had been in potatoes in 1912 and was known to produce a scabby crop. The seed was placed in hills made with a hand hoe and the material to be tested was scattered in the hill with the seed tubers. Duplicate tests of each material were made, in the most cases using 20 hills in each series. Green Mountains were planted in 1912 and Early Rose in 1913. Both lots were disinfected in 1 ounce of formaldehyde in 2 gallons of water for 2 hours.

The mature potatoes were dug and examined. Records were made of the weights rather than of the numbers of the tubers. The total weights of unscabbed tubers, of those badly scabbed and of those slightly scabbed, will be found in the accompanying tables viii and ix on page 61.

A careful study of the yields from the various plots will make it clear that the effect of the chemicals used was not nearly as marked as those noted by other experimenters. In 1912, a slight decrease in the percentage of clean tubers resulted from the use of the slaked lime, while the increase in percentage of tubers not scabbed resulting from the use of barnyard manure and sulphur amounted to less than 10 percent and may have been due to accidental variation in the experimental plots. Even less can be said of the effects of chemicals and manure in 1913. A small increase in the percentage of clean tubers over that of the controls resulted from practically all the treatments tested. It is doubtful if these results are at all conclusive. The

work must be repeated for a number of years on a variety of soils before it will be safe to recommend any of these treatments for general practical work. It should be pointed out, however, that the results might have been different if trials were conducted for a long and unbroken series of years on the same plot. At the present time the only thing that can be said of the results is that no chemical applied for a single season seems under the conditions obtaining during the trials to exert any marked effect on the scab organism in the soil.

SUMMARY OF OUR KNOWLEDGE ON THE EFFECT OF CERTAIN SOIL TREATMENTS ON POTATO SCAB

Since, as has been pointed out, experiments and observations strongly indicate that certain chemicals and fertilizers influence to a marked degree the extent of potato scabbing, it seems advisable to collate these observations and to summarize not only the results above cited but also the work of others. Among the more important and more commonly used materials are: barnyard manure, lime, ashes, sulphur, potash salts, nitrate of soda and bone meal. The most extensive investigations in the matter of scab prevention in this country have been made by Halsted (28, 29, 30, 31, 32) at the New Jersey Station. In this connection attention is called to the tables which set forth the results attained in many sections and under varied conditions.

The tabulations display among other information the test conditions (kind of soil, previous usage, and fertilizer usage other than of the specific substances tested). The first column of figures shows the percent of tubers scabbed in the test rows; the second, the percent of tubers scabbed in the check rows; and the third, the percentage differences. The plus sign indicates increased scabbing following treatment and the minus sign indicates reduced scabbing following treatment.

Barnyard manure undoubtedly favors scabbing, as indicated herein (page 55) in trials by Beckwith (2), Kinney (39), Halsted (28), Lamson (43), Sturgis (69) and others. The extent of scabbing in soil rich in humus depends somewhat on other conditions, such as moisture, etc. Beckwith has shown that barnyard manure used in relatively dry soils increased scabbing by 9 percent, whereas under conditions similar save that irrigation was practiced, the scabbing was increased 49 percent. This was undoubtedly due to the more rapid decomposition of the manure induced by the increased soil water content. As has already been indicated Morse and Halsted have shown that barnyard manure from animals fed on scabby potatoes is liable to

contain the scab organism, and Thaxter points out that the organism grows readily or luxuriantly in a water extract from horse dung.

The reason for this increase when manure is used is difficult to explain, since its mode of action is not clearly understood. Furthermore the same type of action does not invariably follow its use. To the alkaline reaction of lime, ashes, marl, etc., is usually attributed their scab-producing tendencies, but manure is generally supposed to increase soil acidity, which theoretically should reduce the tendency towards scabbing. It would seem as if its ill effect may be due to the mechanical and physiological action of manure. It improves a soil's tilth, aeration and water-holding powers and augments the organic matter content and affords conditions most favorable to the development of the scab organism. See table i, page 55.

Lime has long been known to aggravate scabbing. Indeed many early observers supposed that its chemical effects on the potato produced the trouble. Beckwith (2), Halsted (28), Wheeler (76), Lamson (43) and others have studied this question. A few cases are recorded wherein liming showed a tendency to reduce scabbing or to have been inactive, but usually the reverse has been true, sometimes as high as 40 percent increase or more being noted. Liming is deemed a preventive of some soil and plant ills, but it should not be used on potatoes. Its malign influence is doubtless due to its action on the soil. It tends to promote porosity, to increase water-holding powers, to liberate other plant nutrients and to neutralize soil acidity. This latter effect is important since the organism best develops in an alkaline or very slightly acid habitat. See table ii, page 56.

Ashes. Wood ashes have repeatedly increased scabbing, and are listed among the early writings as causing or aggravating the malady. Halsted, however, failed to indicate such an effect. On the other hand Wheeler (77) and Lamson (43) show a decided increase in scab when they were applied. Beckwith (2) found that coal ashes reduced scabbing as much as 26 percent.

Since ashes (other than coal ashes) are alkaline, one would expect them to increase scabbing; but they also contain some potash, which in some combinations tends to decrease scabbing. In other words, some of their constituents may and others may not aggravate scab. See table iii, page 57.

Potash salts. Kainit is a natural Stassfurt salt carrying 20 percent of potash which is used extensively in fertilization. It almost invariably reduces or tends to control the ravages of potato scab.

Halsted (28) carried on extensive experiments on badly infected soil. In one series there was from 37 to 42 percent less scabbing where kainit was used than where it had not been applied. However, he found that when used at the rate of 1500 pounds or more per acre it injured the crop, and, furthermore, that soaking the seed in a kainit solution proved as effective as did its free use as a fertilizer.

The manufactured Stassfurt salts, muriate and sulphate of potash, seem almost invariably to reduce scabbing. Beckwith (2) and Taft (72) show material gains in this respect by their use in the potato hills. Whether these results were due to the potash contents of these salts or not is not clear, but this appeared to be the one common factor. See table iv, page 58.

Bone meal. No extensive trials have been made with bone meal, yet Beckwith (2) believes that scabbing is increased by its use. Bone meal may be taken as a form of phosphatic fertilizer and this, taken with the figures of Lamson which show that "phosphate" increased scab, may indicate that phosphatic fertilizers favor potato scabbing. See table v, page 58.

Sulphur may be considered at least as a partial preventive, although this statement is not universally accepted. Beckwith (2), Halsted (28), and Sturgis (67) show an invariable reduction of scab following its use at the rate of 150 or 300 pounds per acre, or where moist seed tubers were rolled therein, the benefit varying from 7 to 46 percent and in one case as high as 95 percent. On the other hand trials by Brooks (8), Garman (23) and Taft (72) indicate that sulphur is ineffective or worse. The great majority of experiments recorded indicate that under most conditions sulphur, used at the rate of 300 pounds per acre or as a coating to seed tubers, tends to reduce scab ravages. Doubling this dosage according to Halsted (28) did not materially lessen the scab, increased the cost and slightly injured the crop. The value of sulphur no doubt lies in its fungicidal nature, as several sulphur derivatives may form in the soil, such as sulphuric and sulphurous acids. See table vi, page 59.

Wheeler (78) has shown that sulphur applied to acid soils or to those poor in basic materials, may be injurious to succeeding crops. He believes that sulphate of ammonia may be applied advantageously as a scab preventive without injuring succeeding crops.

Miscellaneous materials. Numerous other materials have been tested by various workers, some of which were found to encourage scabbing while others seemed to retard it. Among those substances

which have reduced scabbing are, hyposulphite of soda, common salt, and corrosive sublimate; among those which increased it are, nitrate of soda, wheat bran, and sawdust. See table vii, page 60.

The results obtained by Stone and Chapman (71) with a variety of chemicals seem inconclusive, but sulphur and a commercial by-product called "by-product A" produced some favorable results.

POTATOES RESISTANT TO SCABBING

The growth of immune or disease resistant plants, if such can be developed, is to be preferred to recourse to various treatments of ordinary non-resistant sorts, which even at the best afford only temporary relief. Just what it is that renders a plant disease resistant is not always clear. It may be dependent upon the physiological nature of the host plant and to some extent, undoubtedly, depends on its morphological structure. Unfavorable surroundings may cause it to become more susceptible to disease by lowering its vitality and impairing its health. Morphological factors are obviously easier to deal with than are the physiological factors. Potato scab is a disease of the cork and outermost layers of the starch parenchyma. Naturally, therefore, these structures as they occur on different varieties of potatoes have been studied with reference to their relation to potato scab. The color of the skin, whether dark, light or pink and white, and its thickness have been compared with the susceptibility to scab of divers varieties. The range of variation of the disease resistance of the sorts tested seem somewhat wide; but this phase of the matter needs no discussion here as no work has been done by the writers, but reference in this connection should be made to the extensive series of statements as to diseases resistance of potatoes to scab, on pages 159-165 in bulletin 179 of this Station. Beckwith (2), Humphrey (38), Kinney (39), Rane and Hunt (56), Halsted (33), Craig (16), Williams (79), Sheppard and Ten Eyck (61), Norton (54) and Stuart (66) may be mentioned among those who have published data. The virulence of the organism is so dependent on the chemical and physical conditions of the material in which the tubers are grown, that any series of varieties comparatively studied as to their disease resistance to scab must be grown under widely diverse soil and climatic conditions before the results can be accepted as conclusive. Isolated tests, such as have just been cited, if properly conducted, contribute to our knowledge; but much more confirmatory evidence must be secured before one will be justified in vaunting any particular variety as disease resistant.

TABLE I—EFFECT ON SCABBING OF USE OF BARNYARD MANURE

Author	Station and date	Soil, climatic conditions, etc.	Details as to special treatment	Percentage scabbed tubers on trial area	Percentage scabbed tubers on check area	Percentage increase or decrease in scabbing; total crop = 100
Beckwith	N. Y. '87	Garden, irrigated, dry season	Before plowing	71.	22.	+49.
Beckwith	N. Y. '87	Garden, dry season	Before plowing	30.	21.	+ 9.
Kinney	R. I. '91	Loam, natural drainage, grass, rich	Underneath	26.4	13.7	+12.7
Kinney	R. I. '91	Loam, natural drainage, grass, rich	Above	44.5	13.7	+20.8
Halsted	N. J. '95	Previous year's crop badly scabbed	"Full amount"	85.	47.	+38.
Halsted	N. J. '95	Previous year's crop badly scabbed	"Half amount"	50.	47.	+ 3.
Halsted	N. J. '95	Previous year's crop badly scabbed	"Quarter amount"	75.	47.	+28.
Halsted	N. J. '95	Previous year's crop badly scabbed	Scattered in hill	55.	47.	+ 8.
Lamson	N. H. '97	Commercial fertilizer on control	Quantity not given	14.	37.	—23.
Lamson	N. H. '98	No potatoes for years; seed disinfected	Quantity not given	20.	5.	+15.
Lamson	N. H. '98	No potatoes for years	Quantity not given	40.	19.	+21. (a)
Sturgis	Conn. '96	Not recently in potatoes; soil supposedly scab free	Fresh	73.	50.	+23. (a)
Sturgis	Conn. '96	Not recently in potatoes; soil supposedly scab free	Composted (old)	60.	50.	+10. (a)
Sturgis	Conn. '96	Not recently in potatoes; soil supposedly scab free	Fresh	74.	40.	+34. (b)
Sturgis	Conn. '96	Not recently in potatoes; soil supposedly scab free	Composted (old)	68.	40.	+28. (b)

(a) Dug early, Sept. 14. (b) Dug late, Oct. 20.

TABLE II—EFFECT ON SCABBING OF USE OF LIME

Author	Station and date		Soil, climatic conditions, etc.	Details as to special treatment	Percentage scabbed tubers on trial area	Percentage scabbed tubers on check area	Percentage increase or decrease in scabbing; total crop = 100
Beckwith	N. Y.	'88	Garden, manured; check unmanured........	Air slaked; tablespoonful per hill	89.	47.	+42.
Halsted	N. J.	'95	Previous year's crop very scabby............	Slaked; 300 bu. per acre......	85.	47.	+38. (a)
Halsted	N. J.	'95	Previous year's crop very scabby............	Slaked; 150 bu. per acre......	15.	47.	—32. (b)
Halsted	N. J.	'95	Previous year's crop very scabby............	Slaked; 75 bu. per acre	90.	47.	+43.
Halsted	N. J.	'95	Previous year's crop very scabby............	Slaked; potatoes rolled in....	50.	47.	+ 3.
Wheeler *et al.*	R. I.	'95	Pot trials; full plant food ration used.......	Air slaked; 2½ tons per acre..	98.4	23.5	+74.9
Lamson	N. H.	'98	Not recently in potatoes....................	Air slaked	11.	10.	+ 1.
Lamson	N. H.	'98	Not recently in potatoes....................	Air slaked	53.	27.	+26.
Lamson	N. H.	'98	Not recently in potatoes....................	Air slaked	0.	5.	— 5.
Lamson	N. H.	'98	Not recently in potatoes....................	Air slaked	42.	19.	+23.
Wheeler *et al.*	R. I.	'93	Sandy loam, gravelly subsoil...............	Air slaked; 5,400 lbs. per acre.	47.7	15.7	+32.
Wheeler *et al.*	R. I.	'93	Sandy loam, gravelly subsoil...............	Air slaked; 5,400 lbs. per acre.	48.5	3.3	+45.2

(a) Crop injured; only 75% stand. (b) Crop injured; only 80% stand.

TABLE III—EFFECT ON SCABBING OF USE OF ASHES

Author	Station and date		Soil, climatic conditions, etc.	Details as to special treatment	Percentage scabbed tubers on trial area	Percentage scabbed tubers on check area	Percentage increase or decrease in scabbing; total crop = 100
Beckwith	N. Y.	'88	Garden, in field	Coal ashes, handful per hill	18.	44.	—26.
Halsted	N. J.	'95	Cabbages; ashes used in '94	Wood, ashes, 300 bu. per acre, '94	100.	100.	0.
Halsted	N. J.	'95	Cabbages; ashes used in '94	Wood ashes, 150 bu. per acre, '94	100.	100.	0.
Halsted	N. J.	'95	Cabbages; ashes used in '94	Wood ashes, 75 bu. per acre, '94	100.	100.	0.
Wheeler *et al.*	R. I.	'95	Pot trials; full plant food ration used	Wood ashes; calcium equi. ½ ton per acre	100.	23.5	+76.5
Lamson	N. H.	'98	Not recently in potatoes; seed disinfected	Wood ashes	30.	10.	+20.
Lamson	N. H.	'98	Not recently in potatoes; seed not disinfected	Wood ashes	66.	27.	+39.
Lamson	N. H.	'98	Not recently in potatoes; seed disinfected	Wood ashes	5.	5.	0.
Lamson	N. H.	'98	Not recently in potatoes; seed not disinfected	Wood ashes	72.	19.	+53.

TABLE IV—EFFECT ON SCABBING OF USE OF POTASH SALTS

Author	Station and date		Soil, climatic conditions, etc.	Details as to special treatment	Percentage scabbed tubers on trial area	Percentage scabbed tubers on check area	Percentage increase or decrease in scabbing; total crop = 100
Beckwith	N. Y.	'87	Garden, manured, irrigated, dry season	Muriate, ½ oz. per hill	80.	84.	— 4.
Beckwith	N. Y.	'87	Garden, irrigated, dry season	Sulphate, ½ oz. per hill	63.	84.	—21.
Beckwith	N. Y.	'87	Garden, manured, dry season	Muriate, ½ oz. per hill	20.	47.	—27.
Beckwith	N. Y.	'87	Garden, manured, dry season	Sulphate, ½ oz. per hill	25.	47.	—22.
Beckwith	N. Y.	'87	Garden	Sulphate, ½ oz. per hill	43.	44.	— 1.
Taft	Mich.	'90	Sandy, well decomposed muck, loose	Sulphate, 2 lbs. per 1½ rods	47.	53.	— 6.
Taft	Mich.	'90	Sandy, well decomposed muck, loose	Sulphate, 2 lbs. per 1½ rods	93.4	100.	— 6.6
Halsted	N. J.	'95	Previous year's crop badly scabbed	Kainit, 3,000 lbs. per acre	8.	47.	—39. (a)
Halsted	N. J.	'95	Previous year's crop badly scabbed	Kainit, 1,500 lbs. per acre	5.	47.	—42. (b)
Halsted	N. J.	'95	Previous year's crop badly scabbed	Kainit, 750 lbs. per acre	10.	47.	—37.
Halsted	N. J.	'95	Previous year's crop badly scabbed	Kainit, seed soaked in	5.	47.	—42.
Halsted	N. J.	'95	Previous year's cabbage badly clubbed	Kainit, 2,000 lbs. per acre	100.	100.	0.
Halsted	N. J.	'95	Previous year's cabbage badly clubbed	Kainit, 1,000 lbs. per acre	100.	100.	0.
Halsted	N. J.	'95	Previous year's cabbage badly clubbed	Kainit, 500 lbs. per acre	100.	100.	0.

(a) Crop injured; only 25% of normal stand. (b) Crop injured; only 50% of normal stand.

TABLE V—EFFECT ON SCABBING OF USE OF BONE MEAL

Beckwith	N. Y.	'87	Garden, manured, irrigated, dry season	Tablespoonful per hill	85.	84.	+ 1.
Beckwith	N. Y.	'87	Garden, manured, dry season	Tablespoonful per hill	86.	47.	+39.
Beckwith	N. Y.	'88	Garden	Handful per hill	56.	44.	+12.
Beckwith	N. Y.	'88	Garden	¼ handful per hill	49.	44.	+ 5.
Taft	Mich.	'90	Sandy and mucky, loose and open	4 lbs. per 1½ rods	53.	53.	0. (a)
Taft	Mich.	'90	Sandy and mucky, loose and open	4 lbs. per 1½ rods	100.	100.	0. (a)

(a) Two pounds sulphate of potash per row.

TABLE VI—EFFECT ON SCABBING OF USE OF SULPHUR

Author	Station and date		Soil, climatic conditions, etc.	Details as to special treatment	Percentage scabbed tubers on trial area	Percentage scabbed tubers on check area	Percentage increase or decrease in scabbing; total crop = 100
Beckwith	N. Y.	'88	Garden soil, in field	Cuttings moistened and rolled	18.	44.	—26.
Beckwith	N. Y.	'87	Garden soil, manured, irrigated	Tablespoonful per hill	56.	84.	—28.
Beckwith	N. Y.	'89	Garden soil, manured	Tablespoonful per hill	19.	47.	—28.
Taft	Mich.	'90	Sand and muck, loose	7½ ozs. per 1½ rods	64.	53.	+11.
Halsted	N. J.	'95		7½ ozs. per 1½ rods	95.	100.	— 5.
Halsted	N. J.	'95	Previous year's crop very scabby	600 lbs. per acre	5.	47.	—42. (a)
Halsted	N. J.	'95	Previous year's crop very scabby	300 lbs. per acre	1.	47.	—46.
Halsted	N. J.	'95	Previous year's crop very scabby	150 lbs. per acre	1.	47.	—46.
Halsted	N. J.	'95		Potatoes rolled in	5.	47.	—42.
Halsted	N. J.	'95	Cabbages, previous year	300 lbs. per acre	5.	100.	—95.
Garman	Ky.	'98			52.2	42.9	+ 9.3 (b)
Chester	Del.	'98	Known to be scab infected	300 lbs. per acre	12.4	26.8	—14.4
Chester	Del.	'98		Seed rolled in	10.2	20.3	—10.1
Brooks	Mass.	'97	Badly infected, seed corrosive subl. treated	300 lbs. per acre, in rows	13.5	1.4	+12.1
Brooks	Mass.	'97	Badly infected	300 lbs. per acre, in rows	100.	100.	0.
Sturgis	Conn.	'98	Previous crop, 75% scabbed; clean seed	Seed rolled in	35.	56.	—21. (c)
Sturgis	Conn.	'96	Previous crop, 75% scabbed; scabby seed	Seed rolled in	36.	74.	—38. (c)
Sturgis	Conn.	'96	Previous crop, 75% scabbed; scabby seed	Seed rolled in	25.	32.	— 7. (d)
Sturgis	Conn.	'96	Previous crop, 75% scabbed; scabby seed	Seed rolled in	45.	54.	— 9. (d)
Sturgis	Conn.	'96	Not recently in potatoes, supposedly scab free	Seed rolled in 230 lbs. per acre	19.	50.	—31. (c)
Sturgis	Conn.	'96	Not recently in potatoes, supposedly scab free	Seed rolled in 230 lbs. per acre	23.	40.	—17. (d)
Halsted	N. J.	'98	In potatoes '96, '97, '98; 240 lbs. sulphur in '96	480 lbs. per acre	10.	60.	—50. (e)
Halsted	N. J.	'98	In potatoes '96, '97, '98; 480 lbs. sulphur in '96	360 lbs. per acre	15.	60.	—45. (e)
Halsted	N. J.	'98	In potatoes '96, '97, '98; 120 lbs. formalin in '97	720 lbs. per acre	15.	60.	—45. (e)
Halsted	N. J.	'98	In potatoes '96, '97, '98; 360 lbs. sulphur in '96	360 lbs. per acre	10.	60.	—50.
Jones, Edson	Vt.	'04	Light sandy loam, mostly never cultivated	500 lbs. per acre	7.	22.	—15
Stone, Chapman	Mass.	'13	23 inch tiles used	50 grams per tile	70.	85.	—15.
Stone, Chapman	Mass.	'13	23 inch tiles used	200 grams per tile	60.	85.	—25.

(a) Vitality slightly injured. (b) Average 5 tests. (c) Dug early, Sept. 4. (d) Dug late, Oct. 20. (e) Control received 120 lbs. benzine.

TABLE VII—EFFECT ON SCABBING OF USE OF MISCELLANEOUS MATERIALS

Author	Station and date		Soil, climatic conditions, etc.	Details as to special treatment	Percentage scabbed tubers on trial area	Percentage scabbed tubers on check area	Percentage increase or decrease in scabbing; total crop = 100
Beckwith	N. Y.	'88	Garden soil	Nitrate of soda ½ oz. per hill	48.	44.	+ 4.
Beckwith	N. Y.	'88	Garden soil	Bran, handful per hill	61.	44.	+17.
Beckwith	N. Y.	'88	Garden soil	Sawdust, handful per hill	60.	44.	+16.
Beckwith	N. Y.	'88	Garden soil	Common salt	33.	44.	—11.
Halsted	N. J.	'95	Well tilled, previous year's crop scabby	Corrosive sublimate, 120 lbs. per acre	5.	47.	—42.
Halsted	N. J.	'95	Well tilled, previous year's crop scabby	Corrosive sublimate, 60 lbs. per acre	5.	47.	—42.
Halsted	N. J.	'95	Well tilled, previous year's crop scabby	Corrosive sublimate, 30 lbs. per acre	2.	47.	—45.
Halsted	N. J.	'95	Well tilled, previous year's crop scabby	Corrosive sublimate, seed soaked in	1.	47.	—46.
Halsted	N. J.	'95	Previous cabbage crop, badly clubbed	Corrosive sublimate, 30 gals. of 1:1000 sol. per acre	88.	97.	— 9.
Halsted	N. J.	'95	Previous cabbage crop, badly clubbed	Gas lime, 150 bus. per acre	100.	100.	0.
Halsted	N. J.	'95	Previous cabbage crop, badly clubbed	Gas lime, 75 bus. per acre	100.	100.	0.
Halsted	N. J.	'95	Previous cabbage crop, badly clubbed	Gas lime, 37½ bus. per acre	...	100.	0.
Taft	Mich.	'90	Sandy, loose soil, well decomposed muck	Hyposulphite of soda, 12 ozs. per 1½ rods	77.	100.	—33.
Halsted	N. J.	'95	Well tilled, previous year's crop scabby	Copper sulphate, 300 lbs. per acre	5.	47.	—42.
Halsted	N. J.	'95	Well tilled, previous year's crop scabby	Copper sulphate, 150 lbs. per acre	5.	47.	—42.
Halsted	N. J.	'95	Well tilled, previous year's crop scabby	Copper sulphate, 75 lbs. per acre	2.	47.	—45.
Halsted	N. J.	'95	Well tilled, previous year's crop scabby	Seed soaked in copper sulphate sol.	1.	47.	—46.

TABLES VIII AND IX—EFFECT ON SCABBING OF USE OF SUNDRY FERTILIZERS, ETC., AT VERMONT STATION. VIII, 1912; IX, 1913

Treatment	Weight of potatoes in pounds				Percentage			Percentage increase or decrease in scabbing
	Total	Not scabbed	Badly scabbed	Slightly scabbed	Not scabbed	Badly scabbed	Slightly scabbed	
VIII, 1912								
Barnyard manure, a heavy application scattered in the rows	27.0	24	0.5	2.5	88.9	1.8	9.3	— 8.9
	26.0	22	3.0	1.0	84.6	11.5	3.9	— 4.6
Fresh unslaked lime, a heavy application scattered in the rows	25.5	21	4.5	0.0	82.3	17.7	0.0	— 2.3
	32.0	18	8.0	6.0	56.3	25.0	18.7	+23.7
Slaked lime, scattered in the rows	25.0	10	10.0	5.0	40.0	40.0	20.0	+40.0
	29.0	20	3.0	6.0	69.0	10.3	20.7	+11.0
Sulphur, 300 pounds per acre scattered in the rows	25.5	22	1.0	2.5	86.3	3.9	9.8	— 6.3
	23.0	20	0.0	3.0	86.9	0.0	13.1	— 6.9
Mixed fertilizer, per acre scattered in the rows	25.5	19	4.0	2.5	74.5	15.7	9.8	+ 5.5
	23.0	20	3.0	0.0	86.9	13.1	0.0	— 6.9
Controls	22.5	18	2.0	2.5	80.0	8.9	11.1	
	20.0	16	0.0	4.0	80.0	0.0	20.0	
IX, 1913								
Lime, 150 bushels per acre......	26.6	5.6	3.0	18.0	21.0	67.7	11.3	+ 6.7
	34.3	12.8	0.8	20.7	37.3	60.3	2.4	— 9.6
Common salt 300 pounds per acre	21.4	8.6	1.0	15.8	33.7	62.2	3.9	— 6.0
	27.7	6.1	0.0	21.6	22.0	78.0	0.0	+ 5.7
Potato phosphate (mixed fertilizer) 2 tons per acre........	14.5	5.2	0.0	9.3	35.9	64.1	0.0	— 8.2
	16.7	9.8	0.0	6.9	58.7	41.3	0.0	—31.0
Mixed fertilizer, 2 tons per acre	12.3	3.1	0.3	8.9	25.2	72.4	2.4	+ 2.5
	3.3	2.6	0.4	0.3	78.8	9.1	2.1	—51.1
Bone meal, 1½ tons per acre...	31.2	12.3	2.4	16.5	39.4	52.9	7.7	—11.7
	34.2	9.0	1.2	24.0	26.3	70.2	3.5	+ 1.4
Potassium nitrate, 600 pounds per acre	15.0	5.8	0.8	8.4	38.7	56.0	5.2	—11.0
	21.3	9.1	0.1	12.1	42.7	56.9	0.4	—15.0
Sulphur, flowers of, 600 pounds per acre	31.7	12.3	1.2	18.2	38.8	57.4	3.8	—11.1
	36.5	8.5	0.0	28.0	23.3	76.7	0.0	+ 3.4
Copper sulphate, 600 pounds per acre	29.2	15.0	3.4	10.8	51.4	56.9	11.7	—23.4
	27.5	6.1	0.0	21.4	22.2	77.8	0.0	+ 5.5
Copper sulphate, 600 pounds, and lime, 100 bushels per acre..	27.5	12.5	1.8	13.2	45.4	48.0	6.6	—17.7
	27.4	11.3	0.3	15.8	41.2	57.7	1.1	—13.5
Potato phosphate, 2 tons and lime, 100 bushels per acre..	23.0	11.0	0.0	12.0	47.8	52.2	0.0	—20.1
	15.7	7.8	0.0	7.9	49.7	50.3	0.0	—22.0
Potassium nitrate, 600 pounds lime, 100 bushels per acre..	22.4	9.2	0.0	13.2	41.1	58.9	0.0	—13.4
	5.8	3.6	0.0	2.2	62.1	37.9	0.0	34.4
Barnyard manure, a heavy application	20.8	7.3	1.4	12.1	35.1	58.2	6.7	7.4
	24.9	8.4	0.0	16.5	33.7	66.3	0.0	6.0
Controls	33.1	9.1	0.8	23.2	27.5	70.1	2.4	.....
	31.5	8.8	0.9	21.8	27.9	69.2	2.9	.....

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